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NAVAL ORDNANCE AND GUNNERY

Volume 2—FIRE CONTROL

BUREAU OF NAVAL PERSONNEL

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NAVAL ORDNANCE AND GUNNERY

VOLUME 2—FIRE CONTROL

Prepared by the Department of Ordnance and Gunnery
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PREFACE, VOLUME 2

Naval Ordnance and Gunnery (1955) is a basic textbook on the subject of naval weapons and their control. Prepared for use primarily as a classroom text for midshipmen at the United States Naval Academy and in the Naval Reserve Officers Training Corps, it will also serve to support other officer and officer candidate training programs and will have general use as a reference book.

This text is limited to a treatment of fundamental concepts and principles of ordnance, with enough data on typical weapons and control systems for the purposes of the training programs for which it is intended. It is not intended to replace technical and doctrine publications of the Bureau of Ordnance and the Office of the Chief of Naval Operations.

The present edition is a revision of *Naval Ordnance and Gunnery* (1950), originally a *Restricted* book. Because of the cancellation of the *Restricted* security classification, the present edition is issued in three volumes: I, *Naval Ordnance*; II, *Naval Fire Control and Gunnery Organization*, and III, *Confidential Supplement*. These are all subtitles, appearing in conjunction with the general title, *Naval Ordnance and Gunnery*. It is considered that the present organization is likely to be more convenient to the users of the book.

The index for volume II is a master index for both unclassified volumes, with the purpose of facilitating cross reference between weapons and control systems. Volumes I and III have indexes keyed only to those individual volumes.

The new material in this publication, and the revision of the book as a whole, were accomplished by officers attached to the Department of Ordnance and Gunnery, U. S. Naval Academy, and by representatives of the departments of Naval Science of four selected NROTC universities, working in conjunction with the Training Division, Bureau of Naval Personnel, and the U. S. Navy Training Publications Center, Washington, D. C.

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Chapter 15

INTRODUCTION TO FIRE CONTROL

A. Historical Preface

15A1. General

Fire control is the technique of delivering effective fire on a selected target. It includes the material, personnel, methods, communications, and organization necessary to harass, damage, or destroy the enemy. Within the Navy, however, the term has been customarily restricted to the control of gunfire, while more specific terms such as *torpedo fire control* and *rocket fire control* are used for other weapons.

The fundamental problem of gun fire control is to direct the gun in such a way that the projectile will hit the designated target. If the target is stationary and close enough, the problem is not difficult. Complications are introduced by increasing the range, by shooting from a moving platform such as a ship, by shooting at moving targets, and by shooting many guns at the same target with centralized control. The increase in range increases the time of flight of the projectile, allowing gravity to exert its influence over a longer period of time and to cause the projectile to fall more and more below the projected axis of the bore of the gun. The increase in time of flight also permits greater accumulation of errors caused by motion of own ship and target or by ballistic factors such as wind and drift. As battle range and target speed increase, requirements for accuracy of original measurements and in more complex computations increase.

15A2. Early fire control

The development of fire control as a science and as an art has been pretty much the product of the last century and a half. Prior to 1800, there was no need for elaborate fire control, because the guns themselves were inaccurate except at short ranges. Battle ranges of the period were *pistol shot* (about 50 yards) and *half pistol shot* (about 20 yards).

Sighting consisted chiefly of setting the guns in azimuth, and of leveling them by eye. Sometimes allowance for the curvature of the trajectory was made by "sighting by the line of metal." This was done by aligning the top of the breech and the top of the muzzle with the point of aim, causing the gun to be elevated by the amount of the taper of the gun from breech to muzzle.

Little attempt was made to regulate initial velocity. Powder charges were estimated, and the projectile load was variable. One shot or several shots were used for a charge, and at close quarters guns were frequently loaded to the muzzle with grape.

Nautical gunners became aware of the problem of deck tilt for obvious reasons. One early device for correcting for the roll of the ship was a round shot suspended from a spar. The gunner watched this improvised pendulum swing with the roll of the ship, and just before it was parallel to the mast, he applied his slow match to the touch hole of the piece. Another practice depending upon the roll of the ship was that of firing at the crest of the roll to increase the range.

15A3. Development of fire control

Improvements in fire control were for many years correlated with increases in gun range.

The table at the top of page 2 shows how gunnery ranges have been increased during the past century.

Since these improvements represent specific attempts to develop particular phases of fire control, each of these aspects will be separately treated in the succeeding paragraphs.

15A4. Gun sights

Gun sights introduced early in the nineteenth century consisted of fixed front and rear sight points so adjusted that the line of sight across their tips was parallel to the bore of the gun. The only advantage was a definite means of leveling the gun at the point of aim, although elevation could be adjusted within small limits by regulating the coarseness of the sights taken across the points.

GUNNERY RANGES, 1862–1948

1862	*Monitor* and *Merrimac*	Maximum 1 mile, average 100 yards
1905	Tsushima	4,000—6,000 yards
1910	United States Navy practices	12,000 yards
1915	Dogger Bank opening range	18,000—20,000 yards
1916	United States Navy practices	20,000 yards
1918	End of World War I	24,000 yards
1948	After World War II	40,000 yards plus

Improvements in guns and powder during and after the War Between the States resulted in such increases in range and accuracy that graduated gun sights became a necessity. A movable leaf, adjustable both vertically and laterally, was fitted into the rear sight. Correction for drift caused by the adoption of rifling in big guns was approximated by inclination of the rear sight bracket.

Toward the end of the nineteenth century, the sight telescope was developed. The sight telescope was mounted in such a way that the line of sight could be offset from the axis of the bore of the gun to correct for range, drift, and relative motion of gun and target. Elevation scales were graduated in accordance with proving-ground data, and the weight and composition of powder charges were carefully regulated. An improvement in operation was effected by installing two sights and dividing the responsibility of keeping on target between the *pointer* in elevation, and the *trainer* in train.

15A5. Development of fire control instruments

Naval gunnery practices demonstrated the need of precise measurement of quantities basic to the solution of the fire control problem and to exact and continuous computation. It is of interest that the first steps were taken by young officers who were concerned with practical performance.

Range measurement. When it was found that estimation of range was no longer sufficiently accurate, mechanical aids were sought. The first of these was the stadimeter, adapted to this purpose by 1898. The stadimeter was crude, and was accurate only for short ranges, but it embodied a principle used later in the coincidence rangefinder, which provides sufficient accuracy for surface fire control under good visibility conditions. Later the stereoscopic rangefinder was developed, giving equal accuracy for surface targets and making it possible to range on fast-moving air targets. Recently radar has carried range accuracy out beyond the shooting limit of the guns, and is not dependent upon clear visibility.

Computing devices. The largest and most important corrections in fire control are those that compensate for the relative motion of own ship and target. This relative motion usually causes continuous, and sometimes rapid, change in values of range, relative bearing, and in case of air targets, elevation. Since there are two distinct time lags between the initial determination of the line of sight and the actual impact or burst of the projectile—the time lag between the initial measurement and the solution of the problem, including transmission of the orders to the gun, and the time of flight of the projectile—relative motion will introduce enough error to cause a miss if its effects are not predicted and properly taken into account.

It is, of course, possible to compute on paper, for a specific set of conditions, the correct gun positioning orders in elevation and deflection for any one particular instant. This method is still used for post-firing analysis, but never was of much value in actual practice, as it takes too long and provides no means of continuing the solution to correct original errors or to include further change in the position of the target.

Early in the twentieth century, an improvement in computation was brought about by graphic plotting. A graphic plot (for a surface target) consists of a series of ranges and bearings of the target, set down on paper, from which it is possible to determine the approximate course and speed of the target. This method provided a valuable supplement to the paper computation, but was soon supplanted by a further refinement, which plots range against time. The advantage of this procedure is that it makes possible the determination of the rate at which range is changing (range rate) and so makes it feasible to predict the range at the end of the time of flight. In practice, the fire of main-battery guns was controlled in this way for a time, but the important contribution of graphic plotting was that it established the basic principle of the mechanical rangekeeper.

Briefly, this basic principle is that if present range is determined, and if the rate and direction at which range is changing can be computed from the speeds and courses of target and own ship, then the range at a later instant can be determined by computing the change of range for any convenient time interval and adding this change of range to the original value of observed present range, assuming that the range rate remains constant during the period of the computation. This computation can be used to keep the range up to date while the problem is being solved, and to *predict* for change during the time of flight of the projectile.

The most elementary rangekeeper, consequently, has mechanisms for entering observed present range, for determining the range rate, for multiplying the range rate by increments of time, and for accumulating the changes of range. This process is called *generating present range.* The element of time is supplied by building a clock into the rangekeeper.

The same reasoning can be applied to bearing. The observed value of relative bearing becomes the starting point of the computation. The bearing rate (the rate at which bearing is changing) can be computed and multiplied by increments of time, and the resulting increments of bearing can be used to modify the original value of bearing.

Actually, the simplest mechanical rangekeeper ever used by the Navy, the "Baby Ford", was designed to perform these three functions: (1) computing range rate, (2) computing bearing rate, and (3) generating present range.

Once the fundamental rangekeeper was adopted, the natural course of development was to add mechanical means of adjusting for wind, gun ballistics, and variations from standard initial velocity; to add the third dimension of elevation for air targets, and to generate elevation in AA rangekeepers; to refine the method of correcting initial errors in observed values; and generally to shorten the time required for solution.

Corrections for deck motion. A solution for the problem of firing accurately from a rolling and pitching ship did not appear until World War I. This solution depends upon the second important adaptation of a child's toy—the gyroscope—to Navy use.

The gyro's property of maintaining its spin axis fixed in space was first used on shipboard in the gyrocompass, which always points to true north and is not affected by the magnetic fields of the ship. The gyro compass itself is important in fire control, as it establishes a system of polar coordinates from which the relationship of own ship and target motion to the earth may be determined.

To correct in fire control for the inclination of the deck caused by the roll and pitch of the ship, the property of gyroscopic rigidity is again used. A gyroscope is so mounted that, as its axis of spin establishes and maintains the true vertical, it makes possible the establishment of a reference plane in the horizontal. The position of the ship with respect to this reference plane is measured and fed into the computer as constantly changing inputs to the problem.

Communications systems. Since the equipment and stations comprising a fire control system are widely dispersed for various reasons (visibility, protection, *etc.*) adequate communications are very important. As fire control installations became more complex and elaborate, the relaying of shouted orders gave way first to rubber hose stretched between stations, then to metal voice tubes; but neither was satisfactory. The first reliable system was the telephone, which has the necessary clarity and flexibility. Sound-powered telephones and interior communications systems make it possible for a control officer to talk to whole groups of men at many stations. Today, communications have become a major factor in the coordination of ship and gun control. A special station for the collection, evaluation, and dissemination of combat information called the Combat Information Center (CIC) has been established to assist the commanding officer in planning a correct course of action, and to assist Command and Fire Control in the execution of that plan. It handles the innumerable transmissions of intelligence within the ship and from outside.

In addition to the telephone systems, which are adequate for voice commands, fire control makes great use of a variety of mechanical and electrical means of communicating information from one station to another. These include mechanical shafting, buzzers, light signals, and synchro systems for transmitting gun orders and other quantities that may be represented as angular displacements.

15A6. Director control

Under the old system of pointer fire, each gun was practically an independent unit. Each gun crew worked out its own sight settings, and except for being told when to commence and when to cease firing, each gun crew fired at will. As fire control and communications improved, it became evident that a single control officer should direct the work of the battery. From his elevated station he could estimate or measure range, could transmit sight settings to the guns, and could observe the fall of shot and estimate corrections known as *spots.*

It soon became evident that with all guns firing individually it was almost impossible to spot with any accuracy. Buzzers were later used at all the guns to give the signal for firing. This was an improvement, but the guns still went off at various times during the sounding of the buzzer. The next step was the installation of a master firing key in series with the firing circuits of all the guns. When that master key was closed, all ready guns fired.

The control station soon became much more than a station from which verbal orders were issued. A new instrument called a *director* was installed there. This was at first a pair of "master gun" sights that were offset by the necessary lead angles and sighted on the target. The movements of these sights were transmitted electrically to the gun mounts, which duplicated sight motion by matching pointers. Later a director having a built-in analogue computer, one part of which became known as a "dummy gun," was used. The movements which positioned the dummy gun were transmitted to the mounts, to be followed in elevation and train by matching pointers or, in later installations, by automatic control equipments.

The dummy gun idea was eventually given up, but the director remains. It has taken on new functions, such as measuring range, bearing, and elevation, and spotting or otherwise correcting the solution of the problem.

Today the quantities measured at the director are sent to the computer in a protected plotting room below decks. The computer, in addition to solving the fire control problem and transmitting the gun orders to the gun, also sends signals to the director to keep the sights positioned on the target if the solution is correct. If the solution should be in error, some director systems are provided with devices whereby discrepancies between the ordered positioning rates of the director and the actual rates of the target can be measured and introduced as corrections to the computer's solution. This procedure is known as *rate control.*

15A7. Spotting the fall of shot

As battle ranges have increased, increasing importance has been assumed by spotting, or observation of the actual fall of shot. Optical spotting was found to be inadequate at long range, even from the highest station on the ship. Kite balloons were tried in World War I, but proved to restrict ship maneuvers too greatly. Spotting planes were found effective for spotting in range, but not in deflection. Radar has proved to be the best means to date for spotting, as it is almost perfect in range and reasonably accurate in deflection.

15A8. Flexibility of control

Today, gunfire is almost independent of ship maneuvers, and is not, as in the past, limited by tactics. By providing duplicate control and computing stations, batteries can be divided to cover several targets at once or may all be directed at the same target. Further, the destruction of any one station does not make it impossible for the battery to continue its fire.

15A9. Aircraft fire control

Within the memory of many living men, the airplane has developed from an amusing and improbable experiment to the point that the air arm has achieved full parity with the Army and the Navy, and within the Navy itself it has become virtually axiomatic that command of the air over the sea is requisite to the control of the sea.

The carrier provides a floating base for tactical aircraft, making it possible, within the limited range of fighter planes and bombers of suitable size, to employ them tactically in naval battle with the fighting ships themselves completely hidden from each other over the horizon, as was the case in the battles of the Coral Sea and Midway in World War II, or to give tactical support to troops and to maul supply lines far inland, as was proved by the Korean conflict.

As aircraft have become heavier and faster, the variety of weapons carried has increased, comprising guns, bombs, rockets, and torpedoes. Development of aircraft capabilities has caused a corresponding evolution of fire control instruments, as solution time for the problem has become shorter. Individual gun sights and bombsights are being displaced progressively by complete fire control systems. Some of these will be discussed in detail in a later chapter of the present book.

B. Modern Fire Control Systems

15B1. Batteries

For a long period, the batteries of a single ship frequently consisted of guns of various sizes. Because of the difficulty of controlling and spotting the fire of so many batteries, the practice of using guns of the same size and ballistic characteristics in a given battery was adopted. This practice also resulted in a simplified system of supply for ammunition and replacement parts.

The size and number of guns in a battery depends upon the type of ship. Batteries are generally referred to as:

Main battery. The guns of the largest caliber aboard a ship. The term is sometimes extended to indicate the weapon of greatest potential effect. For example, the main battery of an aircraft carrier is its planes; of a submarine, its torpedoes; of certain landing craft, the rocket battery.

Type and Class	*Main Battery*	*DP Battery*	*MG Battery*
BB —*Iowa* class	9 16″/50 cal.	20 5″/38 cal.	All types and classes: many 3″/50 cal., 40-mm and 20-mm
CVB —*Midway* class	....	18 5″/54 cal.	
CV —*Essex* class	....	12 5″/38 cal.	
CB —*Alaska* class	9 12″/50 cal.	12 5″/38 cal.	
CA —*Des Moines* class	9 8″/55 cal.	12 5″/38 cal.	
CL —*Cleveland* class	12 6″/47 cal.	12 5″/38 cal.	
CL(AA)—*Oakland* class	12 5″/38 cal.		
DD —*Gearing* class	6 5″/38 cal.		
DE —*Butler* class	2 5″/38 cal.		

Dual-purpose battery. The largest caliber of guns aboard which are adaptable for use against either aircraft or surface targets. In ships which have a single-purpose main battery, the dual-purpose battery may be called the secondary battery. Many other ships have a dual-purpose main battery.

Machine-gun battery. Permanently emplaced automatic weapons of all calibers, used chiefly against aircraft.

Some typical examples of combatant ship gun batteries are shown in figures 15B1 and 15B2.

15B2. Fire control systems

The exact composition and arrangement of a ship's fire control system depend upon such factors as the type of ship and the size, number, purpose, and effective range of its guns In general, fire control systems have the following characteristics:

1. The primary method of fire is director fire. When the number and arrangement of guns in a battery permits, the battery may be controlled from one station, or the fire may be divided and controlled from several points against multiple targets.

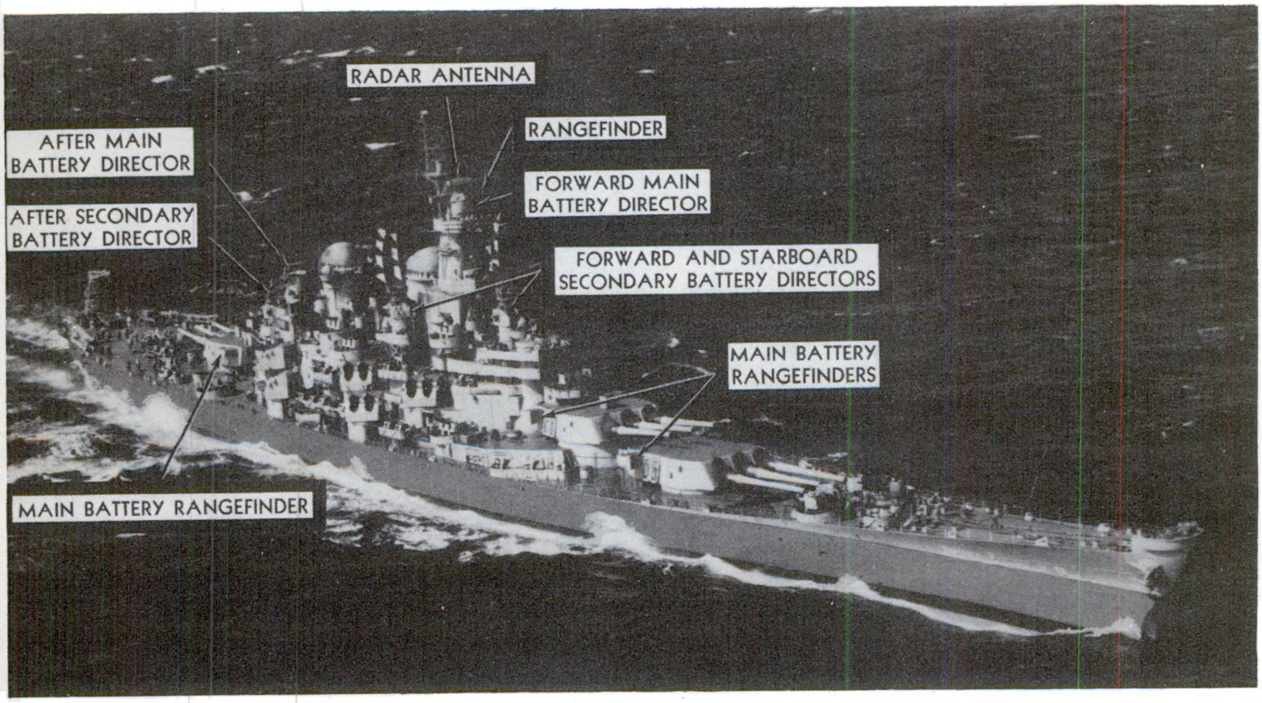
RADAR ANTENNA
AFTER MAIN BATTERY DIRECTOR
RANGEFINDER
FORWARD MAIN BATTERY DIRECTOR
AFTER SECONDARY BATTERY DIRECTOR
FORWARD AND STARBOARD SECONDARY BATTERY DIRECTORS
MAIN BATTERY RANGEFINDERS
MAIN BATTERY RANGEFINDER

FIGURE 15B1.—Battleship fire control installations.

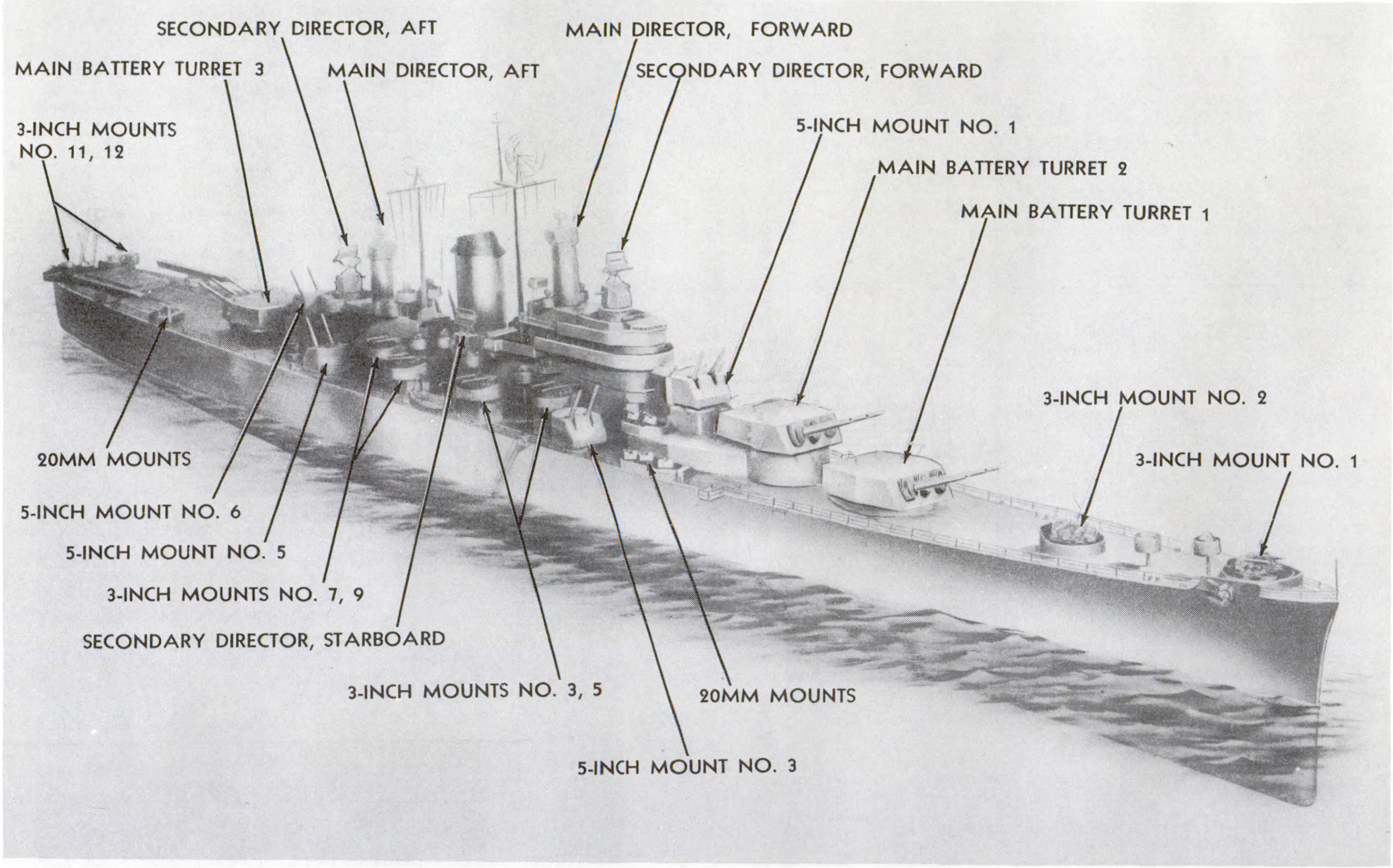

FIGURE 15B2.—USS *Salem* armament arrangement.

2. Provision is made for observations to establish present target position and to spot the fall of shot.

3. Computers figure the predicted position of the target, the ballistic corrections, and corrections to compensate for roll and pitch of the ship. These data are used to compute gun orders in train and elevation which are transmitted to the guns.

4. Gun orders keep the guns constantly positioned in space, ready to fire whenever the firing key is closed.

5. Provision is made for stand-by methods of control if the primary method is inoperative.

6. Efficient communications are provided, with duplicate systems for transmitting information.

7. Provision is made for control of the battery at night, including the control of star shells and searchlights.

15B3. Battleship systems

Figure 15B1 shows a typical modern battleship, in which the location of the principal director emplacements is indicated. The two primary main-battery directors are the highest on the ship, the forward one being about 120 feet above the waterline, the after one about 75 feet. Either director, together with equipment in the plotting rooms, can control all or part of the main battery. Also, any one of the four secondary-battery directors can be used to control all or part of the main battery. In addition, equipment in each turret permits individual, but less effective, control of the turrets independently of the directors and plotting rooms. Five optical rangefinders, one in each main-battery director and in each turret,* provide main-battery ranges. Fire control radars in the fire control tower and in each main-battery director provide radar range (and bearing) for the main battery.

Below the waterline are the forward and after plotting rooms, each of which contains rangekeepers, stable verticals, graphic rangekeeping devices, switchboards, and other instruments. Information is received in plot from the radars, rangefinders, and directors, and is combined with other information obtained from various sources. Computed quantities are transmitted to the guns for their control. Either plotting room may control any part of the battery. Auxiliary computing equipment is provided in each of the three turrets, so that each may fire independently in the event of casualty to both plotting rooms.

The secondary battery has four directors, three of which show in the illustration. The fourth is hidden from view by the forward stack. Each of these directors has its own rangefinder and radar, and may control all or any part of the dual-purpose battery. There are two secondary (dual-purpose) battery plotting rooms similar to those of the main battery, except that they contain no graphic plotting devices. Each is equipped with two computers, two stable elements, the necessary indicating instruments, and switching equipment. With director-controlled fire it is possible to engage four secondary battery targets simultaneously with independent illumination control.

The heavy machine-gun battery is equipped with a separate director and fire control system for each of its mounts. Many of the directors are equipped with radar. Decentralized control permits firing at many targets at once, and facilitates target acquisition. Flexibility of control is provided by cross connections permitting the heavy machine-gun directors to control the adjacent dual-purpose mounts, and the secondary-battery directors to control the heavy machine-gun mounts.

The light machine guns (20-mm) are equipped with individual lead-computing sights.

15B4. Cruiser and destroyer systems

Cruisers have fire control installations similar to those of battleships, except that there are only two directors for the dual-purpose battery (i. e., the secondary battery on cruisers with turrets; the main battery on AA cruisers). Destroyers have only one director and one plotting room for the dual-purpose (main) battery. The control of dual-purpose and machine-gun batteries on cruisers and destroyers is similar to that on battleships, but they can engage a smaller number of targets simultaneously, because of the smaller number of guns and directors.

15B5. The fire control problem

The principal subject of the next several chapters is the *fire control problem.* This term has come to mean the entire series of measurements and computations used in the control of weapons, beginning with the designation of the target and the type of fire, and ending with the destruction of the target. For all batteries, the problem of gun fire control is solved in five steps:

1. *Establishing the present position of the target.* The first step in the solution of the problem is to establish the present position of the target with relation to the ship by measuring its range, bearing, and, for air targets, elevation.

---

*Radar has replaced the optical rangefinders in the turrets of some of the later cruisers.

2. *Computing lead angles.* Lead angles in elevation (called sight angle) and in bearing (called sight deflection) are computed to allow for wind, gun ballistics, and relative motion of own ship and target during the time of flight of the projectile. This is the principal function of all rangekeepers and computers.

3. *Correcting for motion of gun platform.* Corrections are computed to counteract the effect of the constant rolling and pitching of the ship.

4. *Making up gun orders.* Since the guns are so mounted that they can move only in train and elevation, all the foregoing information is converted into gun positioning orders, and is constantly corrected, so that the guns are continuously positioned for firing.

5. *Correcting fall of shot.* In case of inaccuracy of computation, the projectiles may fail to hit the target. Errors are determined by observation and are corrected by the application of corrections known as spots.

15B6. Presentation of the fire control problem

The fundamental considerations in the solution of the fire control problem are the same for both surface and air targets. Since the surface problem is less complicated, it is considered in this text before the air problem.

It should be clearly understood that the emphasis in this text is upon principles, rather than upon details of specific installations. Descriptions of specific equipment are limited to the most commonly used examples of each type. Further information is to be found in the publications of the Bureau of Ordnance.

Methods of use are subject to change; consequently, this publication describes procedures only as illustrations of the capabilities of the equipment. The practicing gunnery officer is referred to fleet publications of most recent date for guidance in this respect.

It is emphasized that the student is expected to receive only an introduction to fire conrol in this text. The expert gunnery officer is made by constant experience and by the detailed study of all fire control gear with which he is associated, particularly that on his own ship.

15B7. Symbols and definitions

Fire control has developed its own language, and the study of the subject requires familiarity with the definitions and symbols of which this language is composed. Gunnery definitions, as standardized by the Fleet Training and Readiness Branch of the Office of the Chief of Naval Operations may be found in appendix E. They are adequate for general use, but their application varies somewhat among different fire control systems. The Bureau of Ordnance has established standard fire control and torpedo control symbols of a more restricted nature, the most useful of which are to be found in appendix F. Fire control symbols and nomenclature, as used in the sections of this book not limited to specific equipment, have been prepared to agree with the most recent current practice. It should be noted that symbols and nomenclature are subject to modification for individual equipments, and that all symbols, nomenclature, and definitions are subject to change by the Bureau of Ordnance and the Chief of Naval Operations. Throughout this text, symbols and definitions occur as required by the subject matter. In some cases the standard definitions have been paraphrased to make them easier to understand.

Chapter 16

RADAR AND OPTICS

A. Introduction

16A1. Tactical information

Effective operation in combat requires the collection and use of a large body of tactical information. It is desirable to know the location and disposition of all forces, both friendly and enemy, within range of the available intelligence. Before any target can be effectively engaged we must know, among other things, its range, bearing, and elevation, and the rate at which these factors are changing.

This meant that, in World War II, a way had to be found to pick up objects which lay beyond the horizon.

16A2. Sources of tactical information

Radar is the principal source of tactical information on modern warships. It may be used to detect and identify targets, and to measure their range, bearing, and elevation. Optical instruments are a secondary source of such information. In the event of power failure, they become the primary source.

Tactical information, regardless of source, is collected and evaluated by the ship's combat information center (CIC). The functions of CIC are discussed briefly in the last section of this chapter.

B. Principles of Radar

16B1. Definition

Radar is an instrument for determining, by radio reflections, the presence of objects, their range, bearing, and elevation; for recognizing certain of their characteristics; and for employing the data thus obtained. The name RADAR is obtained from the term RAdio Detection And Ranging.

Radars used primarily for other than gunnery purposes are discussed extensively in publications pertaining to duties of officers of the Operations Department, as published by the Bureaus of Ships, Aeronautics, and Naval Personnel, as well as by the Chief of Naval Operations and the fleet commanders. For this reason the general discussion of radar principles herein is greatly abbreviated.

16B2. Theory of radar

A radar set detects targets by sending out pulses of ultra-high-frequency radio wave energy from a high-power transmitter. These pulses are concentrated into a beam (somewhat similar to a searchlight beam) by a directional antenna. When the transmitted energy strikes an object, a portion of it is reflected in much the same manner as the sound wave echo from the face of a cliff. This reflected energy is detected by the receiver through the antenna and then translated into usable information on indicators. The fact that radio waves travel at the constant velocity of light enables us to determine the range by measuring the time which elapses between the transmission and the return of the energy. Since the receiver antenna is directional, so that only those objects in a narrow beam can reflect the energy, we are able to determine the bearing and elevation with sufficient accuracy to direct gunfire.

16B3. Functional components

Radar systems now in existence vary greatly as to details. The principles of operation, however, are essentially the same for all systems.

The radar system (fig. 16A1) consists of six essential components, which may be summarized as follows:

1. The *modulation generator,* or a *modulator,* or a *timer,* supplies the synchronizing signals which time the transmitted pulses and the indicator sweep circuits,

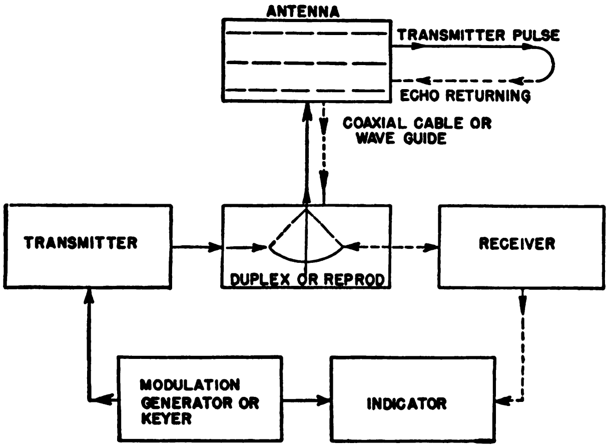

FIGURE 16B1.—Components of a typical radar.

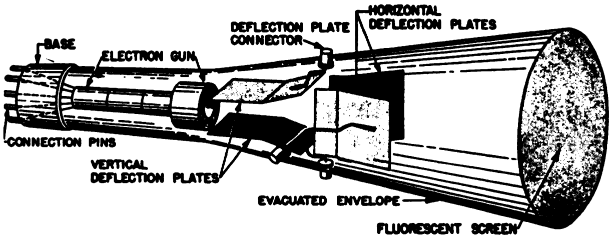
BASE
ELECTRON GUN
DEFLECTION PLATE CONNECTOR
HORIZONTAL DEFLECTION PLATES
CONNECTION PINS
VERTICAL DEFLECTION PLATES
EVACUATED ENVELOPE
FLUORESCENT SCREEN

FIGURE 16B2.—Cathode-ray tube.

and which coordinate the operation of other associated circuits.

2. The *transmitter* generates the radio-frequency energy in the form of short, powerful pulses.

3. The *antenna system* takes the radio-frequency energy from the transmitter, radiates it in a sharply directional beam, receives any returning echoes, and passes these echoes to the receiver. It includes the *duplexer,* which prevents the high-power transmitted signal from damaging the receiver and directs all of the returning signal to the receiver.

4. The *receiver* amplifies the weak radio-frequency pulses returned by the target and reproduces them as video pulses to be applied to the indicator.

5. The *indicator* includes a cathode-ray tube which produces a visual indication of the echo pulses in a manner which presents the desired information.

6. The *power supply* furnishes all a-c and d-c voltages necessary for the operation of the system components.

16B4. Range measurement

Mention has been made of the fact that range is determined by the measurement of the time it takes for a pulse of radio energy to travel to a target, be reflected, and return. Measurement of this time, and thus the range, may be accomplished by the operator after the time has been displayed by means of a cathode-ray tube.

The *cathode-ray tube* is a special type of vacuum tube which acts as an electronic stop watch. As shown in figure 16B2, electrons are channeled into a narrow beam by an *electron gun* in the neck of the tube. The electrons shoot out of the small hole at the right-hand end of the gun and hit the fluorescent screen on the large end of the tube, which glows at the point where the electrons strike. Between the gun and the screen, the electron beam passes between *vertical deflection plates* and *horizontal deflection plates.* If a variable voltage is applied to the horizontal plates, the beam can be made to sweep back and forth in a horizontal line. If a voltage is applied to the vertical plates, the beam can be made to deflect in a vertical direction. If a voltage to the vertical plates is used in conjunction with the voltage to the horizontal plates, a horizontal line deflected upward at certain points can be produced.

This description applies directly to the A-scope described below. In this, the voltage to the horizontal plates is so controlled that the beam of electrons is made to sweep across the screen at a constant rate; thus successive beam positions can be used as a measure of time. In other types of presentation, combinations of vertical and horizontal deflecting currents are used to produce the patterns. All range patterns, however, depend in part upon the fact that the electron beam

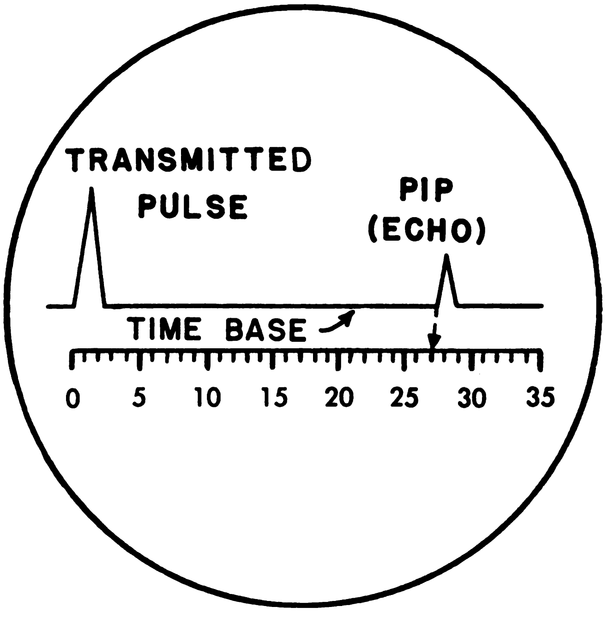

FIGURE 16B3.—A-scope presentation.

can be made to trace across any desired portion of the fluorescent screen during a specific predetermined interval of time.

Radio energy, like light, travels at a speed of 186,000 miles per second. In $\frac{1}{1,000,000}$ second (1 microsecond) it travels 328 yards. If the beam of electrons in the cathode tube is synchonized with an outgoing pulse of radio energy, by the time the pulse has traveled 3,280 yards the beam of electrons has been sweeping across the screen for 10 microseconds. Since the pulse has to travel to the target and return, a time indication of 10 microseconds on the cathode-ray tube represents a range of 1,640 yards, although the pulse has actually traveled 3,280 yards going to the target and returning. Stated in a more convenient fashion, 6.1 microseconds on the scope is equivalent to 1,000 yards in range.

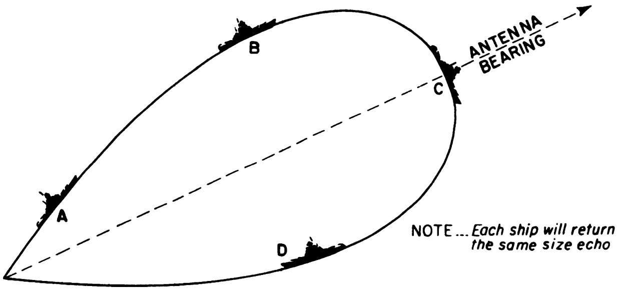

FIGURE 16B4.—Lobe pattern.

Assume that the hypothetical radar set under discussion has a maximum range of 16,400 yards. Then if the beam of electrons is made to travel all the way across the screen in 100 microseconds, the face of the cathode-ray tube can be graduated with zero yards at one end and 16,400 yards at the other end of the sweep. Since the waves travel at a constant speed, the scale can be uniformly graduated from 0 to 16,400.

Actually the movement of each sweep is so fast and the interval between sweeps so short that the eye does not see the individual sweeps but merely a single line of light. In the A-scope presentation (fig. 16B3), the straight line of the sweep extending across the screen is called the *time base.* The small part of the outgoing signal which is allowed to leak through the duplexer causes a large deflection of the light at the left end of the time base; this is called the *transmitted pulse.* The returning target echo is picked up by the sensitive receiver, and the energy is so impressed on the vertical deflection plates of the cathode-ray tube that the beam of electrons is momentarily deflected upward. This makes a *pip* in the time base at a point representing the time at which the echo returns.

The accuracy of the range depends upon the accuracy with which time is measured. To obtain a range accuracy of 3 yards, time must be measured to an accuracy of a hundred-millionth of a second. When time is measured to this accuracy, the range is accurate to 3 yards, regardless of whether the range is 30 or 30,000 yards. This is in contrast to most other types of rangefinding instruments, which have a constant-percentage error in determining the range.

16B5. Determining target direction

The determination of target direction depends upon the characteristics of the radar beam itself. As previously stated, the directional antenna sends out the pulses in a narrow beam. The strength of this beam is greatest in its center, decreasing toward the sides. It also decreases as the distance from the antenna increases. Graphic representation of the strength of radar energy traveling through space is provided by *lobes.* Any given lobe represents the loci of all points in the beam from which identical targets would give echoes of a particular strength, with a fixed direction of antenna. If a target with a standard reflecting surface moved about in a radar beam in such a way as always to produce the same strength echo, it would follow a path (lobe line) as shown in figure 16B4. If lobe lines were drawn to represent echoes of relative strengths **1, 2, 3,** and **4** on any particular size target, they would appear as shown in figure 16B5. Actually, a radar beam is made up of an infinite number of such lobes of varying echo strength. This picture is for a target of one particular size. Naturally a larger target at any of the indicated positions would produce a larger echo.

Figure 16B6 shows how great a change in echo height results simply from sweeping the lobes past the

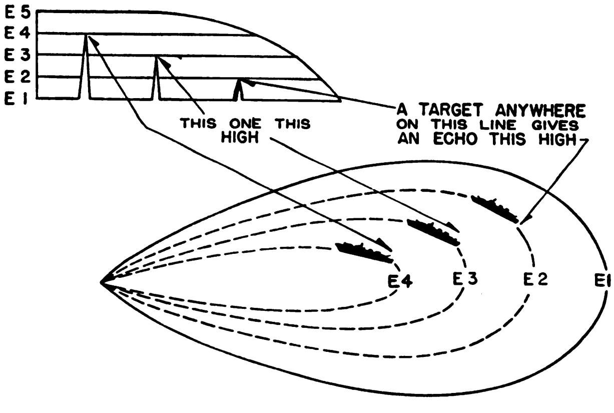

FIGURE 16B5.—Target position and echo strength.

target. In such a movement of the antenna, lobes of greater strength cut the target successively as the antenna axis moves toward it, while lobes of lesser strength cut it while the antenna moves away. The lobes are relatively flat at their ends and steep at their sides; consequently, the echo strength on a particular target changes more per degree of antenna movement (or lobe movement) at the side edge of the lobe than at any other point.

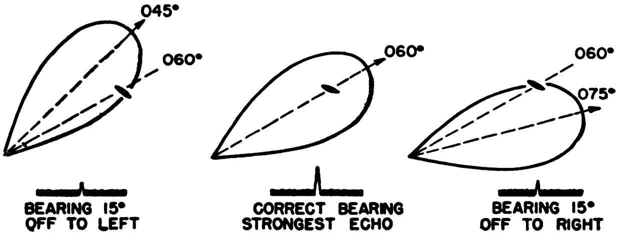

Figure 16B6.—Determining correct bearing by echo's height.

Since the principles used in the determination of bearing and elevation are similar, only bearing determination need be discussed. There are two fundamental methods of bearing determination: (1) the single-lobe or *scanning* method, and (2) the double-lobe or *lobe-switching* method.

The simplest form of antenna for measuring bearing is one which produces a single beam (or a single set of lobes). The antenna is so mounted that it can be rotated. Energy is directed across the region to be searched, and the radar beam is scanned in bearing until a return signal is picked up. The position of the antenna is then adjusted to give the maximum return signal, and the bearing of the center of the antenna is the bearing of the target.

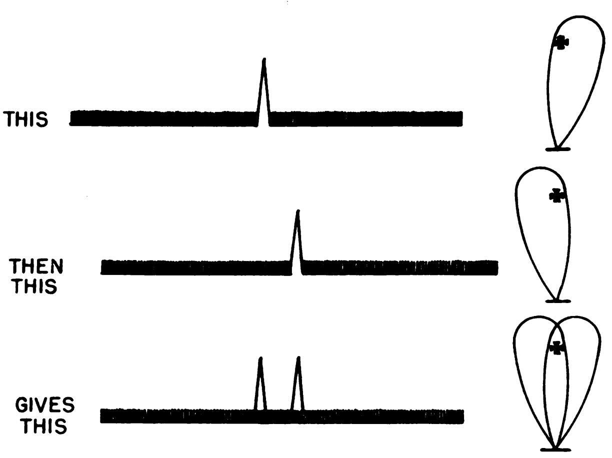

Figure 16B7.—Bearing determination by the double-lobe principle.

The double-lobe principle of bearing determination shown in figure 16B7 depends on the transmission of two identical sets of lobes whose axes are displaced by some fixed angular distance from the antenna bearing. Lobes of equal power intersect at only one point known as the cross-over point. The two beams are transmitted alternately, and each returns a target pip. These pips are presented side by side on the indicator (scope). The sizes of the two pips are compared, and when they are equal, the two beams are striking the target with lobes of equal power, and the antenna axis is pointed directly at the target. If the antenna axis is off target, the inequality in pip size will show the operator which direction to move the antenna to bring it back on target.

16B6. Indicator types

Cathode-ray indicators (called scopes or indicator scopes) may operate on one of two principles, *i. e., deflection modulation* or *intensity modulation.*

Deflection modulation. Typical of the deflection-modulated type is the A-scope already discussed. In this type, the electron beam is moved across the scope in a line, and target returns (pips) are indicated as deflections of this line. The transmitted pulse is also indicated as a deflection. The sweep or electron line is called the time base. The linear distance of the target pip from the transmitted pulse is an indication of the time of travel of the pulse to the target and return. Consequently, the time base may be calibrated to represent the range to the target.

In the double-lobe method of bearing or elevation determination, the deflection-modulated scope is used to show the double target pips.

Intensity modulation. In intensity-modulated scopes, the returning target echo causes an increase in the intensity of the electron stream, rather than a deflection of it. Thus, the target pip appears as a bright spot which may be used to represent combinations of target range and direction by its position on the scope.

Typical of this type of indicator is the *plan position indicator* (PPI) shown in figure 16B8. This scope shows, in polar coordinates, a radar map of the area being covered, with own ship at the center of the screen. Range is indicated by the radial distance from the center of the screen to the illuminated spot (or target pip). The beam or time trace moves radially outward and is also rotated in accordance with antenna rotation through 360 degrees. The top (or 12 o'clock position) of the indicator screen may be set to

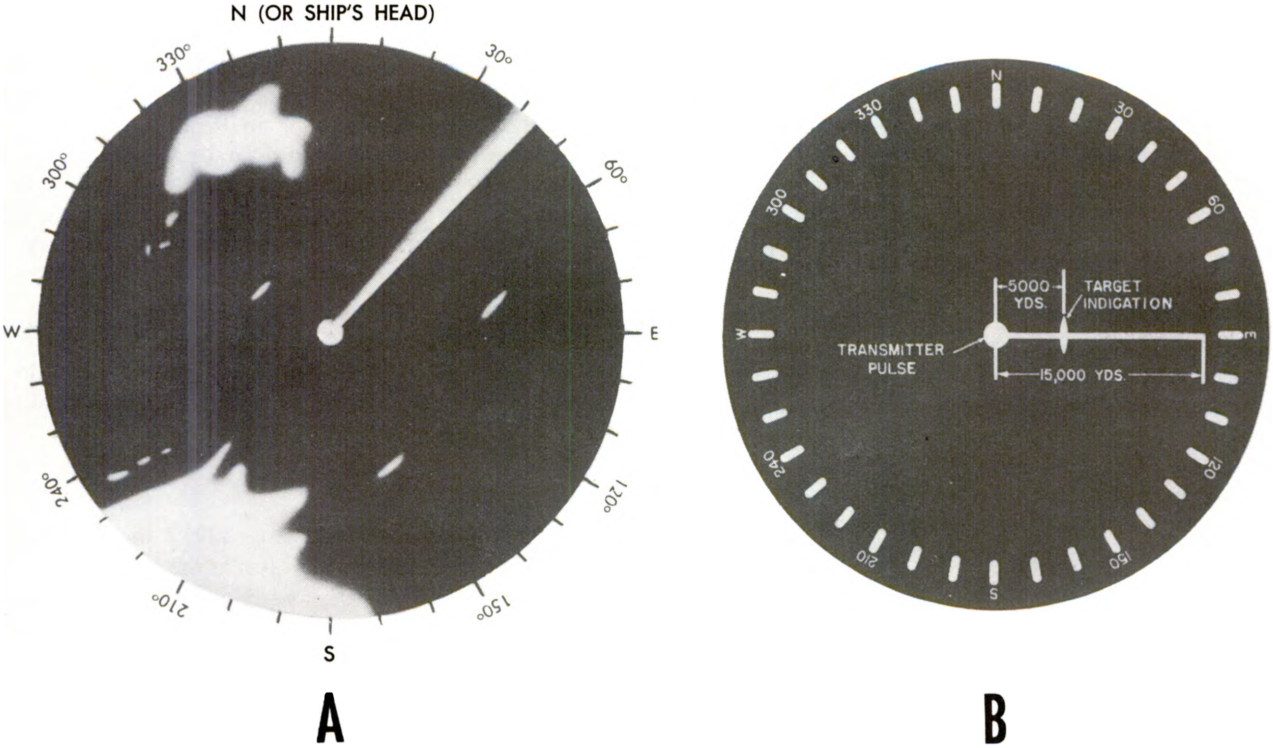

FIGURE 16B8.—PPI-scope presentation.

represent either the direction of ship's bow or true north, so the angular distance of the target echo from the top of the scope is a representation of relative or true target bearing respectively.

The B-scope and T&E-scope (fig. 16B9) are other examples of intensity-modulated scopes. The B-scope provides a rectangular presentation of a small segment of the area, with range indicated vertically and bearing horizontally. The T&E-scope presents a view of a plane perpendicular to the antenna axis, with bearing indicated horizontally and elevation vertically. The presentation is therefore similar to the view through a gun-sight telescope.

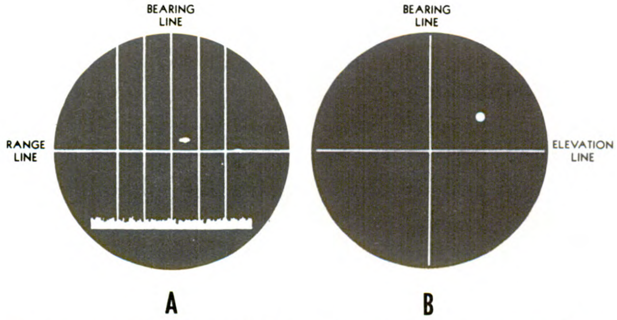

FIGURE 16B9.—Typical intensity-modulated presentations, B-scope and T&E-scope.

C. Types of Radar Equipment

16C1. Search radar

The general class of search radar includes several types of long-range equipment, each of which is designed to fulfill one primary function. The three types most commonly used in surface ships are *air search, height-finding search,* and *surface search.*

An air search radar needs to measure range and bearing to only a fair degree of precision, since its primary function is warning of the presence of aircraft at extreme ranges. Height-finding radar is used primarily for the control of friendly aircraft; for such use it must be capable of discriminating between targets that are close together, and it should be capable of determining range, bearing, and altitude with a fair degree of accuracy. Surface search radar must determine range and bearing of surface targets with moderate precision, in order to assist in navigation and to designate specific targets to the fire control organization.

Air and surface search radars usually use A-scopes for range presentation and PPI's for bearing indication. Height-finding and low-angle search radars also use a special presentation designed to show height and range information together. Most search radars employ the single-lobe method of determining target direction, although the width of the lobes differs considerably between sets.

16C2. Fire control radar

Fire control radar sets must be able to determine the range, bearing, and elevation of a target with a high degree of precision in order to achieve destructive gunfire. They must also have a good target resolution; *i. e.,* they must be able to distinguish between pips which are very close together. This is necessary to permit accurate pointing and training, and spotting of splashes.

Surface fire control radar is used in conjunction with single-purpose main batteries on cruisers and battleships. This radar must measure range and bearing accurately to provide data for the solution of the fire control problem. Bearing is determined by use of the lobe-scanning principle and a B-scope presentation, such as illustrated in figure 16B9 (A). The beam is moved horizontally by oscillating the antenna back and forth rapidly through a small angle. When the radar is on target, the antenna will point at the target in the middle of its arc and the pip will be bisected by the vertical line in the center of the scope. Range is measured by positioning the movable horizontal range line so that it is tangent to the bottom of the pip.

Antiaircraft fire control radar, in addition to supplying range and bearing, must also furnish target elevation. Range is normally read from an A-scope. To obtain bearing and elevation, the radars employ either the scanning or the lobe-switching methods.

In scanning, the beam is caused to rotate in a conical pattern about the antenna axis. A T&E-scope presentation is used, and the antenna is trained and elevated until the target pip appears exactly in the center of the scope.

In lobe switching, the beam is transmitted "right-down-left-up" relative to the axis of the antenna. The right and left beams cause two pips to appear on the trainer's scope, while the down and up beams cause two pips on the pointer's (elevation) scope. When the two pips on the scope are of the same height, the antenna axis is on the target in train or elevation. See figure 16B7.

16C3. IFF

No discussion of radar would be complete which omitted its very important adjunct, IFF (Identification, Friend or Foe).

Radar sets alone are not capable of determining from the reflected echo whether the detected target is friendly or hostile. Hence, the need for identification equipment to work in conjunction with radar sets is apparent. IFF is similar to a small radar, with some of the regular units omitted. In one respect, it is strikingly different: IFF utilizes equipment which must be installed in the target. In using an IFF system, the radar beam from the interrogating ship "triggers" the IFF equipment on the friendly target. The latter equipment then transmits a coded signal which shows up on the indicator scope of the regular radar set on the interrogating ship. Both the interrogating ship and the target must carry IFF equipment. Security is obtained by the use of the coded signals.

16C4. Countermeasures

Every new weapon soon brings about the development of a defensive measure. Just as the night bomber fostered the need for radar, so too were countermeasures developed against radar itself. The new eyes which radar has supplied sometimes can be blinded by skillful countermeasures, in much the same manner as ordinary vision can be blinded by a smoke screen.

The first large-scale use of radar countermeasures took place on 12 February 1942, when the German ships *Scharnhorst* and *Gneisenau* passed through the English Channel under the very nose of the best Allied radar. The ships were not seriously damaged by shore batteries, because the electronic disturbances (*jamming*) confused the radar operators so that the vessels were not tracked by radar. They could not be tracked visually because of the weather.

Jamming is the deliberate production of signals for the purpose of hiding one's movements or position from the enemy's radar by obliterating or confusing the echoes on his indicators. There are two general types of jamming—electronic and mechanical. Electronic jamming is accomplished by the transmission of radio signals, while mechanical jamming is performed by dispersing "window" or some similar substance. "Window" consists of a quantity of strips of metalized paper which cause an echo return. These strips may either be dropped from aircraft, or be dispersed by rockets or projectiles fired from ships.

Either type of radar countermeasure starts with the detection of radar signals by the use of special receivers. By this means the enemy's presence in our vicinity may be detected and some of the characteristics of his radar can be determined. It is then possible to make an intelligent decision as to whether to use jamming techniques and what type to employ.

It must be emphasized that countermeasures, when used against our own radars by the enemy, need not be conclusive. The techniques which are used by an experienced radar operator to read through jamming are beyond the scope of this text. It is appropriate, however, to state that it is always sound doctrine to continue operating a radar, even if the jamming signals received are very effective.

D. Principles of Optics

16D1. Function of optical instruments

The optical instruments used in naval fire control present a magnified image of the target to the observer's eye. At the same time, the observer sees an image of a *reticle,* or reference mark, located inside the instrument itself. By accurately superimposing the reticle image on the target image, the observer can establish an accurate line of sight to the target. The rangefinder, by establishing *two* separate lines of sight, makes it possible to find the target range by triangulation.

To form the reticle and target images, an optical instrument must control the path of the light that passes through it. It does so by the use of lenses, prisms, or mirrors, or some combination of these elements. This section briefly reviews the behavior of light as it passes through optical elements. Familiarity with these basic principles will make possible a general understanding of most optical instruments.

16D2. Nature of light

Light is a form of energy. It travels from one point to another in the form of waves. Except for their wavelengths and frequency, light waves are identical with other types of electromagnetic radiation, such as radio waves and gamma rays. The wavelength of visible light ranges from approximately 0.35 micron to 0.70 micron. (A micron is one thousandth of a millimeter.) The color of light depends on its wavelength. In order of increasing wavelength, the colors are violet, indigo, blue, green, yellow, orange, and red. Radiation of longer wavelength than visible red is called infrared, or heat radiation. Beyond infrared are the radio waves. Radiations shorter than visible violet are, in the order of decreasing wavelength: ultraviolet, X rays, gamma rays, and cosmic rays.

If a small object is dropped into water, a series of concentric circular waves will spread out from the point of impact. This provides a familiar analogy for the behavior of light waves. Waves in water, however, move on a two-dimensional surface; light waves move in three dimensions. The waves that move outward from a small source of light may be thought of as a series of concentric, rapidly expanding spheres.

In the study of optical instruments it is convenient to trace the path of light *rays,* rather than waves. At any given point, a light ray is an imaginary line used to show the direction in which the light wave is moving. Since the wave is an expanding sphere, its direction of movement at any point is along a radius of that sphere. A ray, then, is a radius of the sphere formed by the wave front, and is at right angles to the wave front.

A telescope or similar instrument will receive only a small part of the light emitted by the source. Each wave that enters the instrument, therefore, is only a small part of a sphere. If a wave comes from a nearby source, the part of it that enters the instrument will be strongly curved. And the rays (radii of the spherical wave) that enter the instrument will be diverging. But if the source is at a great distance, the part of the wave that enters the instrument will be nearly flat; for all practical purposes it can be considered a plane. Since the rays are perpendicular to the wave front, the rays that enter an optical instrument from a distant point can be considered parallel. Figure 16D1 should make this clear.

In figure 16D1, the source of light is a single point. But a telescope is most often used to observe fairly

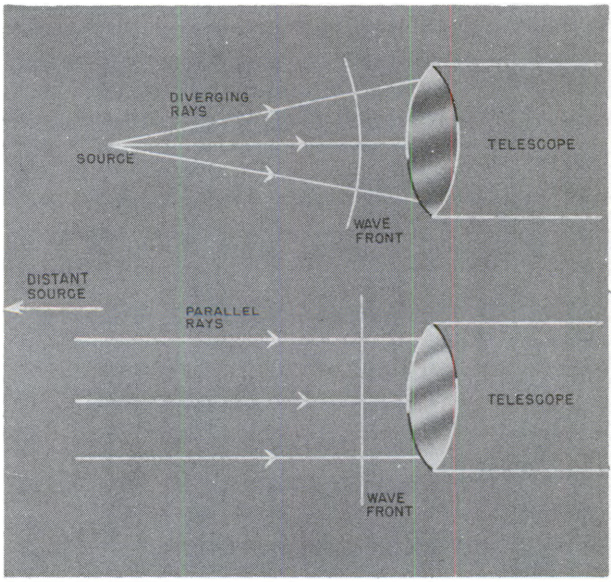

FIGURE 16D1.—Light rays from nearby and distant source.

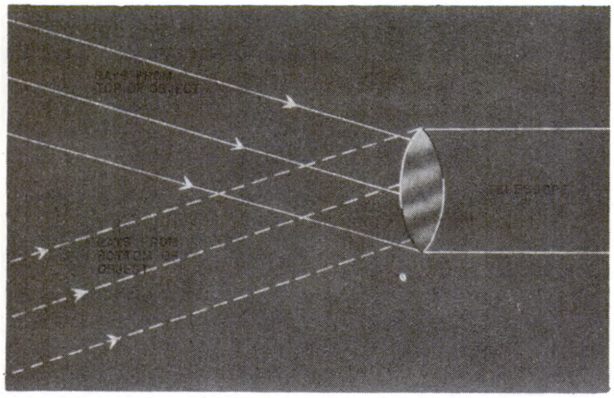

Figure 16D2.—Light rays from a large source.

large objects, such as enemy ships. In this case, of course, not all the rays that enter the telescope will be parallel. But all the rays that enter the instrument from *any one point* on the object will be parallel, as shown in figure 16D2. In this figure, the solid lines represent rays from the top of the object; the broken lines represent rays from the bottom of the object.

Note that in all three drawings only a few rays are used to represent the light that enters the instrument. It should be remembered, however, that light enters an optical instrument at every point on its first lens. Since the spherical wave has an infinite number of radii, an infinite number of rays are striking the lens. In diagrams of optical instruments, only a few of these rays will be shown. Three rays are usually enough to show the path of light, and the formation of images, within the instrument.

Light travels at tremendous speed: approximately 186,000 miles per *second* in air. In a vacuum, its velocity is slightly higher. In a denser medium, it moves more slowly. For example, the velocity of light in water is about 140,000 miles per second; in glass it ranges from 95,000 to 127,000 miles per second, depending on the optical density of the glass. When light passes from one medium into another of different density, its velocity changes. This change in velocity makes it possible for an optical instrument to control the path of light, to form images, and to magnify them.

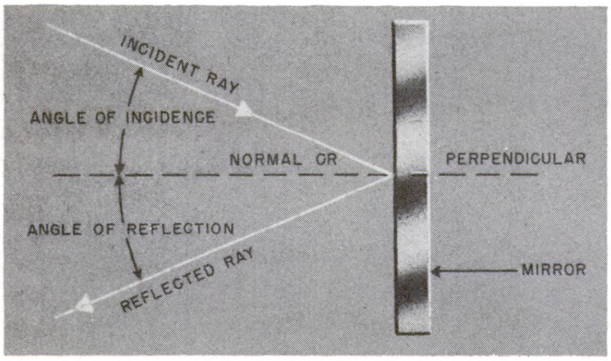

Figure 16D3.—Reflection at a mirror surface.

16D3. Reflection

When light, traveling in air, strikes the surface of a mirror, most of it is reflected back into the air. Figure 16D3 shows the path of a ray of light reflected by a mirror.

This figure illustrates several of the terms used to describe the reflection of light. The incoming ray is the *incident ray.* The *normal* is an imaginary straight line, at right angles to the mirror surface, passing through the point of incidence. The *angle of incidence* is the angle between the incident ray and the normal, and the *angle of reflection* is the angle between the normal and the reflected ray. The *law of reflection* states, first, that the angle of incidence is equal to the angle of reflection; and, second, that the incident ray, the reflected ray, and the normal all lie in the same plane.

When light, traveling in air, strikes the surface of clear glass, a part of the light will be reflected back into the air; the rest will enter the glass. If the incident ray lies on the normal (zero angle of incidence), about 5% of the light will be reflected. As the angle of incidence is increased, the amount of reflection increases. As the angle of incidence approaches 90°, the reflection approaches 100%.

When light, traveling in glass, strikes an air surface, a part of the light will be reflected back into the glass; the rest will enter the air. At zero angle of incidence, about 5% of the light will be reflected back into the glass. As the angle of incidence is increased, the amount of reflection increases rapidly. When the angle of incidence becomes greater than the *critical angle,* all of the light will be reflected back into the glass; none of it will enter the air. (The critical angle for various types of glass, at an air surface, varies from 37° to 43°.) For angles of incidence greater than the critical angle, the inner surface of the glass acts like the mirror in figure 16D3, and the reflection from this surface follows the same laws. This property of a glass-air surface, called *total internal reflection,* is used in many optical instruments.

Mirrors are occasionally used in optical instruments to deviate the line of sight. But, if the angle of incidence is greater than the critical angle, internal reflection at a glass-air surface is usually used for this purpose. Figure 16D4, for example, shows how the line of sight may be deviated through an angle of 90° by internal reflection at the diagonal face of a right-angle prism.

For this purpose, a prism has two important advantages over a mirror. First, a prism may be more rigidly mounted than a mirror, and is thus less subject to misalignment or breakage. Second, the reflecting surface of a prism will reflect all the incident light, whereas a mirror will reflect only about 90%.

An inspection of figure 16D4 will show that if the prism is rotated (in the plane of the page) through any angle, the angle of incidence will be changed by the same angle. The angle between the incident ray and the reflected ray will therefore be changed by *twice* that amount. If a pointer is attached to the prism, it can be made to indicate, on a suitable calibrated scale, the angle through which the line of sight has been deflected.

16D4. Refraction of light

When light passes from air into glass, its speed will decrease. It will resume its original speed when it leaves the glass and enters the air. If a ray of light strikes an air-glass or a glass-air surface at an oblique angle, its change of speed will result in a change of direction. Figure 16D5 shows why this is so.

The diagonal lines in the figure represent the approaching light waves. Since they are coming from a distant source, they are parallel. As each wave enters the glass, various points along the wave front will slow up successively, and as a result the entire wave front will change its angle. Since the direction of movement, shown by the ray, is at right angles to the wave fronts, the light bends as it enters the glass. The opposite effect occurs when the waves leave the glass. Now the various points along the wave successively increase their speed. As a result, the emergent waves are parallel to those that entered the glass. And the emergent ray is parallel to the incident ray, although it has been displaced to one side.

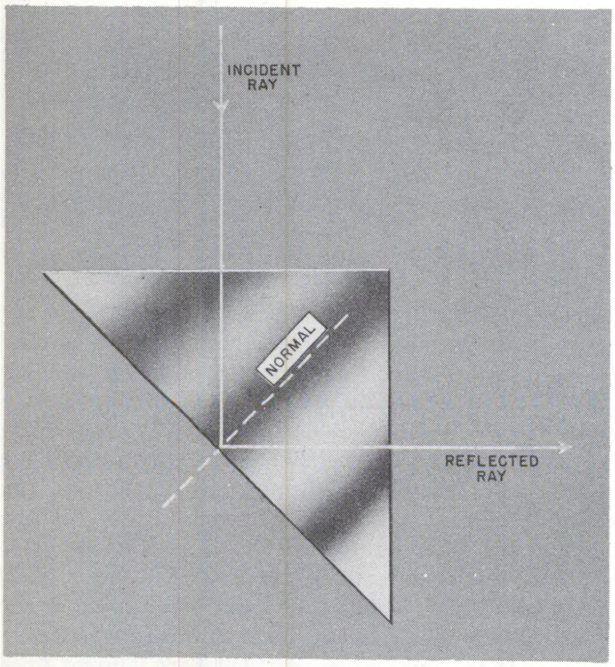

FIGURE 16D4.—Total internal reflection in a prism.

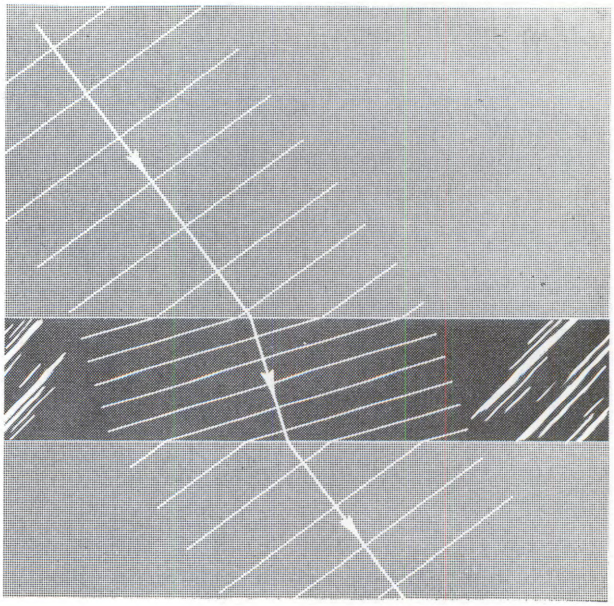

FIGURE 16D5.—Path of wave fronts through a sheet of glass.

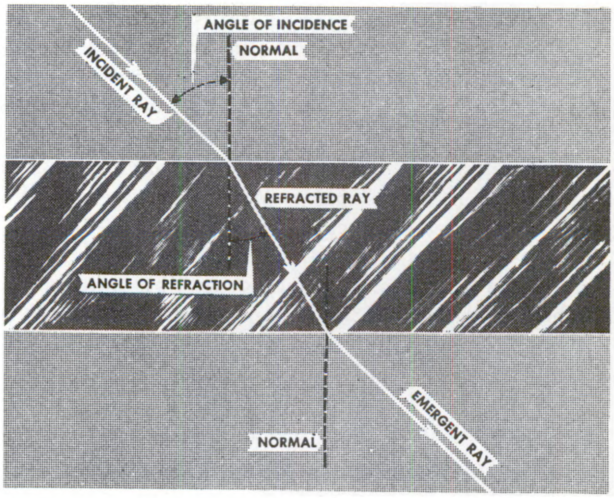

FIGURE 16D6.—Terms used to describe the refraction of light.

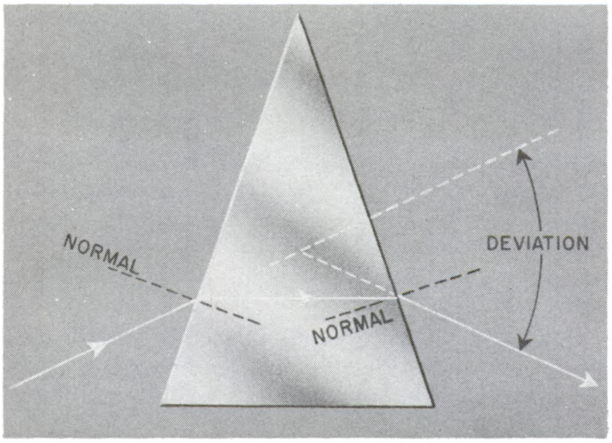

Figure 16D7.—Refraction in a prism.

Figure 16D6 illustrates some of the terms used to describe the refraction, or bending, of light. The *law of refraction* states that light bends toward the normal when it passes into a denser medium; it bends away from the normal when it passes into a less dense medium. The exact angle of bending may be easily calculated. It depends on the angle of incidence, and on the optical density of the two media. Optical density is expressed as *index of refraction*. (The index of refraction of a vacuum is one; the index of refraction of air is approximately one. The various types of optical glass range from approximately 1.5 to 1.96.) The angle of refraction may be calculated from the relation

$$n \sin \theta = n' \sin \theta'$$

where n is the index of refraction of the first medium, n' the index of refraction of the second medium, θ the angle of incidence, and θ' the angle of refraction.

When the two glass surfaces are parallel, as in figure 16D6, the emergent ray is parallel to the incident ray. When such elements occur in optical instruments (as, for example, in the end windows of rangefinders), they do not deviate the line of sight. However, if the two glass surfaces are not parallel, the line of sight will be deviated, as in figure 16D7. When the ray enters the glass at the first surface, it bends toward the normal. As it leaves the glass, at the second surface, it bends away from the normal. The net result is a deviation of the ray toward the base of the prism. Thin prisms are used in rangefinders to deviate the line of sight through a small angle.

16D5. Image formation

Figure 16D8 shows the path of parallel rays of light on passing through two prisms mounted base to base. Each ray will be deviated toward the base of the prism it passes through. As a result, the upper rays are deviated downward, and the lower rays are deviated upward. All the rays emerging from the upper prism are parallel, and all the rays emerging from the lower prism are parallel.

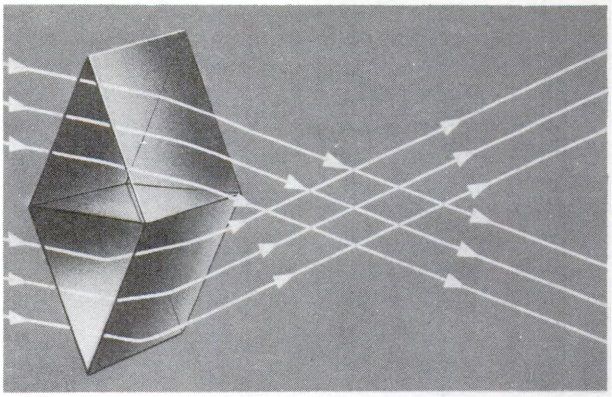

Figure 16D8.—Deviation of rays by two prisms.

If the surfaces of the two prisms in figure 16D8 are rounded off to form a convergent lens, as in figure 16D9, each ray will have a different angle of incidence, and will therefore bend to a different degree. The ray that passes through the center of the lens is normal to both surfaces, and therefore does not bend. Such a ray is said to lie on the *optical axis* of the lens. Rays near the axis will strike each surface at a small angle of incidence, and will be slightly deviated toward the axis. The greater the distance from the axis, the greater the angle of incidence at each surface, and the greater the deviation toward the axis.

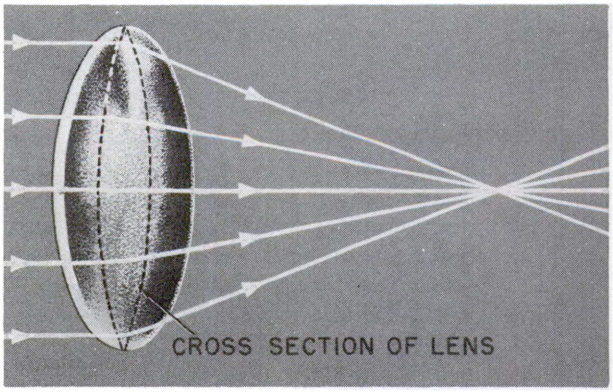

Figure 16D9.—Deviation of rays by a convergent lens.

If the lens is perfect, all rays parallel to the axis will meet at a single point, called the *focal point* of the lens. Every lens has two focal points, one on each side. (If the rays in figure 16D9 were coming from the right, they would meet at a point on the left side of the lens.) The two focal points are equally distant from the lens. The distance from either focal point to the center of the lens is the *focal distance,* or *focal length* of the lens.

By applying the law of refraction at each surface of the lens in figure 16D9, it can be seen that, if a source of light is placed at the focal point, the diverging rays that strike the lens will be deviated toward the axis, and will be parallel when they emerge from the lens. The behavior of light on passing through a convergent lens can be summarized by these statements: parallel rays will be converged to the focal point, where they will cross; convergent rays will be more strongly convergent after passing through the lens; divergent rays will be less divergent after passing through the lens.

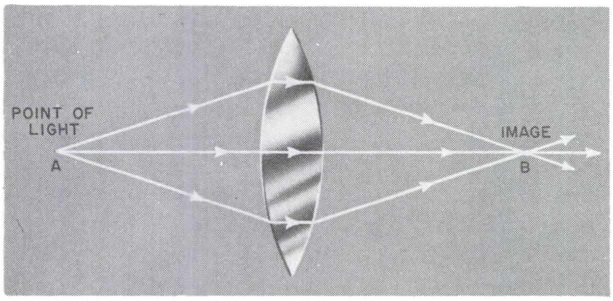

FIGURE 16D10.—Image of a point.

Figure 16D10 shows three rays of light diverging from a point source, and passing through a convergent lens. It should be remembered that an infinite number of rays are striking the lens, but as usual three are enough to show what happens. All the rays from A that pass through the lens converge and meet at point B. Point B is therefore the *image* of A. Note that B is itself a source of light, since rays diverge from it just as they do from A. If a sheet of paper is held at B, the image may be seen as a bright point on the paper. If B lies between the lens and the observer's eye, the image may be inspected directly.

In figure 16D10 it is obvious that the distance from point A to the lens is greater than the focal length. If the source were at the focal point, the rays emerging from the lens would be parallel, and would meet only at infinity. If the source were closer to the lens than the focal point, the lens would make the rays less divergent, but they would never meet.

A target or other object is visible when it reflects light toward the observer. Each point on the target, unless it's black, may be considered a point source of light. For each of these points, a convergent lens will form a corresponding image point, behind the lens. These image points together form a recognizable image of the whole target. In the study of any optical instrument, it is often desirable to know the size and location of the image. This information may be obtained from a scale drawing, as in figure 16D11.

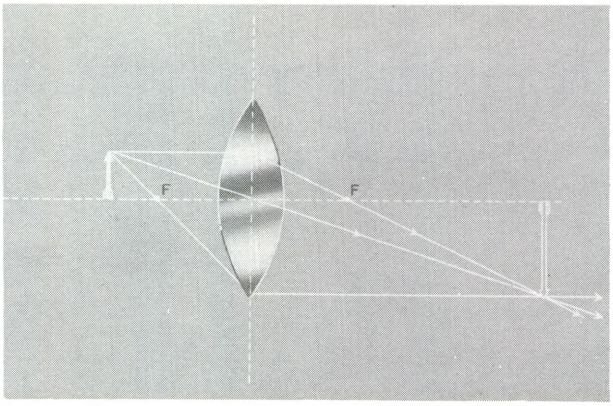

FIGURE 16D11.—Image formation by a convergent lens.

In this figure, the target is an arrow lying to the left of the lens, with its tail on the optical axis. Although refraction takes place at both surfaces of the lens, it may be assumed for the purpose of these drawings that all the bending takes place in a vertical plane through the center of the lens. Since the tail of the arrow lies on the optical axis, the tail of the image will also lie on the axis. It is therefore possible to determine the size and location of the whole image by locating the image of the arrow head. Although an infinite number of rays from the arrow head are striking the lens, it is possible to plot the exact path of three of these rays by using these rules:

1. Any ray that passes through the center of the lens will not be deviated.
2. Any ray that passes through the first focal point will emerge parallel to the axis.
3. Any ray that strikes the lens parallel to the axis will pass through the second focal point.

Obviously, the image of a single point may be located by using any two of these three rays. In figure 16D12, the size and location of the image is determined by plotting the path of two rays from the top of the target, and two rays from the bottom. Note that the image is inverted.

The size and location of the image may be calculated, without the use of a drawing, by using these formulas:

$$\frac{1}{D_o}+\frac{1}{D_i}=\frac{1}{F}\ .$$

$$\frac{S_o}{D_o}=\frac{S_i}{D_i}\ .$$

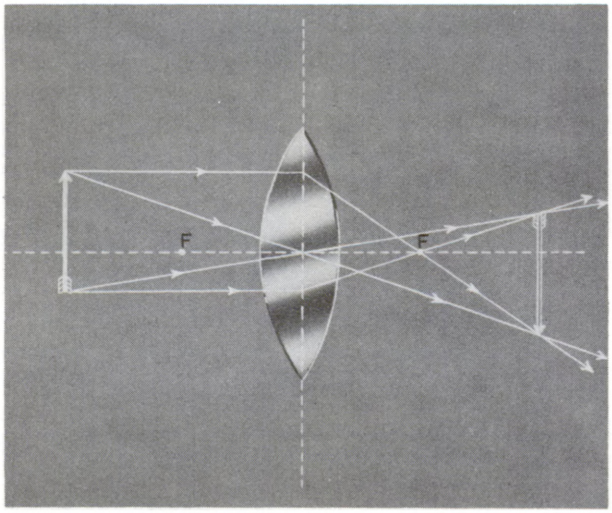

FIGURE 16D12.—Finding the image position.

In these formulas, D_o is the distance from object to lens, D_i the distance from image to lens, F the focal length of the lens, S_o the size of the object, and S_i the size of the image. Of course all quantities must be expressed in the same units.

The application of these formulas will reveal several things:

1. If the object distance is twice the focal length, the image distance will also be twice the focal length, and the image will be the same size as the object.
2. If the object distance is equal to the focal length, the image will lie at infinity, and will be of infinite size.
3. If the object distance is more than one but less than two focal lengths, the image distance will be greater than two focal lengths, and the image will be larger than the object.
4. If the object distance is greater than twice the focal length, the image distance will be more than one but less than two focal lengths, and the image will be smaller than the object.
5. If the object distance is less than the focal length, the image distance will be negative, indicating that no real image is formed.

16D6. Virtual images

Figure 16D13 shows the path of several rays diverging from a point source of light, *O,* when the source lies between the lens and its first focal point. These rays are highly divergent. The lens makes them less divergent, but it does not have the power to bring them to a focus. However, an observer on the right side of the lens may see the point *O* by looking through the lens. Since the observer is accustomed to assuming that light travels in straight lines, it will appear to him that the rays from source *O* are actually coming from point *I*. Point *I* is therefore an image of *O*. However, if a sheet of paper is held at *I,* no image will be formed on the paper. Point *I* is therefore not a real image. No rays actually diverge from *I,* as they do from a real image; they merely ***appear*** to diverge from *I*. Point *I* is said to be a *virtual* image of point *O*. Note that the virtual image is farther from the lens than the object itself.

Figure 16D14 shows how a scale drawing may be used to determine the size and location of a virtual image. The object is the small arrow between the first focal point and the lens, with its tail on the axis. The drawing plots the actual path of two rays from the arrow head. If the two emergent rays are continued backward to the left of the lens, they will intersect at the image of the arrowhead. Note that, whereas the real image formed by a convergent lens is inverted, the virtual image is erect.

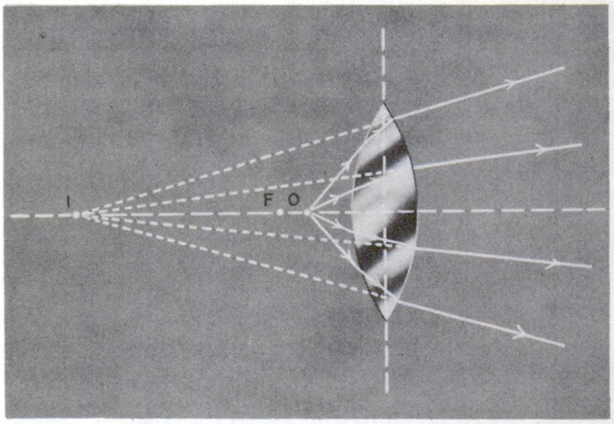

FIGURE 16D13.—Virtual image of a point.

The two formulas given in article 16D5 may be used to calculate the size and location of the virtual image.

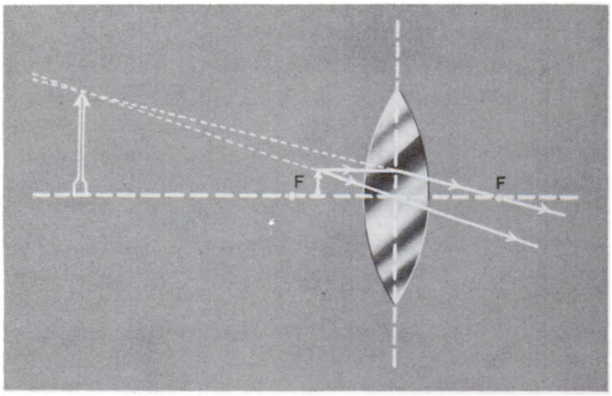

FIGURE 16D14.—Virtual image of an arrow.

The calculated image distance will be negative, indicating that it lies to the left of the lens. The drawing and the formulas both reveal that the image is larger than the object. A single convergent lens may be used, therefore, as a simple magnifying glass.

A magnifying glass is most effectively used by holding it close to the eye. The object distance is adjusted until the image appears in sharp focus when the muscles of the eye are completely relaxed. The object distance will then be equal to the focal length of the lens, and the virtual image will lie at infinity.

16D7 Simple telescope

A telescope is used to provide, to an observer's eye, an enlarged image of a distant object. A simple magnifying glass can not be used for this purpose; as shown in article 16D6, a lens may be used as a magnifying glass *only* when the object under the observation is at or closer than the focal point. As previously stated, a convergent lens may be used to form a real image, which may be examined by the observer. But this real image would appear to the observer as no longer than the object itself. Obviously, then, a single lens cannot be used to provide an enlarged image of a distant object. However, a telescope can be made by using a combination of two or more lenses. The first lens, called the *objective,* forms a real image of the distant object. Since rays diverge from this real image just as they do from the object itself, the observer may examine the real image through a second lens, called the *ocular.* The ocular serves as a simple magnifying glass. It forms an enlarged virtual image of the real image formed by the objective.

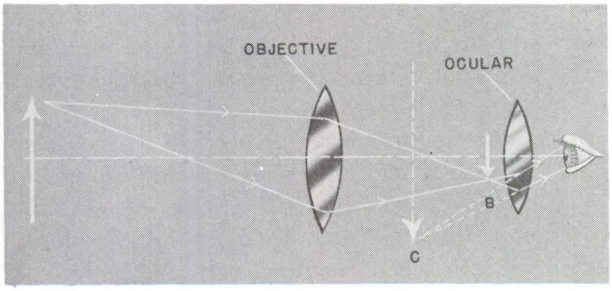

FIGURE 16D15.—Simple telescope.

Figure 16D15 shows the path of rays through a simple telescope. The arrow at the left of the drawing is the target. Actually, it is at a considerable distance from the telescope; it is shown as a nearby object so that the rays diverging from it may be traced through the telescope. The drawing shows two rays from the head of the arrow. These rays are converged by the objective to meet at point *B.* A real, inverted image of the target therefore lies in a vertical plane through *B.* After crossing at point *B,* the two rays diverge and strike the ocular lens. Because this lens is close to *B,* it cannot converge the rays to a point again. However, it does make these rays less divergent. To the observer's eye, these two rays appear to diverge from point *C.* The virtual image seen by the target therefore lies in a vertical plane through *C.* The ocular is usually adjusted so that this image is at infinity; the drawing shows the image at *C* only for convenience. To the observer, the virtual image appears to be considerably larger than the object itself. The telescope therefore forms an enlarged image of the distant object.

The two lenses are, of course, suitably mounted in a metal tube. In some instruments, the ocular is so mounted that the observer may adjust its distance from the objective. This is sometimes necessary, because the position of the real image depends on target distance. The closer the target is to the telescope, the farther the real image will be from the objective. The observer must adjust the position of the ocular until its focal point lies in the plane of the real image. The virtual image will then appear in sharp focus when the observer's eye is relaxed. In other instruments, for example the gun-sight telescope, this focusing adjustment is unnecessary. Since the target is always at a considerable distance, the distance between the objective lens and the image it forms is practically constant.

The real image formed by the objective lens is, of course, inverted. Consequently, the enlarged virtual image seen by the observer in figure 16D15 is also inverted. But if the telescope is to function as a useful fire control instrument, it must present an *erect* image of the target. The image may be erected in either of two ways. One way is to add an *erector lens.* The erector lens is used as a second objective, with the first real image as its target. The erector forms a real image of the first real image. Since, after passing through the erector, the image has been inverted *twice,* the second real image is erect. The ocular then forms an enlarged, erect, virtual image of the second real image.

Many telescopes make use of erector lenses. A few telescopes, and most binoculars, use prisms to erect the image. This is accomplished by means of internal reflection at the various prism faces. Figure 16D16 shows several different ways in which prisms may be used to erect an image. (Note that, in part D of the figure, rays strike the two outside surfaces at less than the critical angle; these surfaces are therefore silvered.)

To provide a fixed line of sight through a telescope, a reticle may be added. The reticle is a flat piece of glass on one surface of which suitable reference

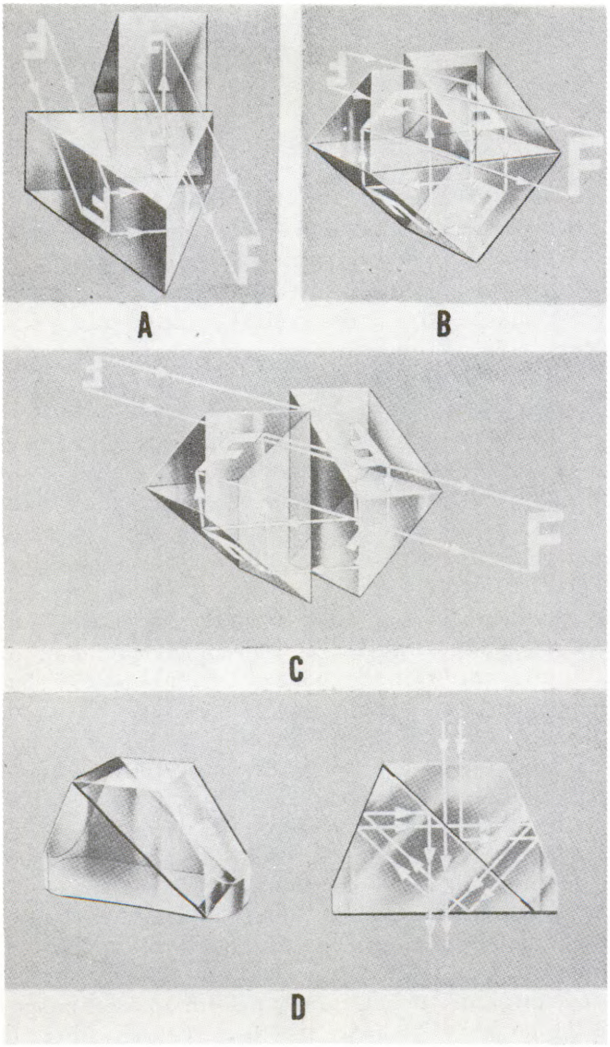

FIGURE 16D16.—Prism erecting systems.

marks, often two lines intersecting at a right angle, have been engraved. The ocular serves as a simple magnifying glass to provide an enlarged virtual image of the reference marks on the reticle. To use the instrument, the observer first adjusts the ocular until he sees a sharp image of the reticle. (If the instrument is a gun-sight telescope, it has been previously adjusted so that the reticle marks lie in the plane of the real image formed by the objective.) The observer will then see a sharp image of the target, with the reticle marks superimposed on it. If the adjustments have been properly made, there will be no relative motion between the target image and reticle image when the observer moves his eye from side to side at the ocular. The observer has, therefore, established a line of sight to the target.

16D8. Correction of aberrations

From the foregoing discussion it would appear that a useful gun-sight telescope could be made with only four optical elements: an objective lens, an erector lens, an ocular lens, and a reticle. The actual instruments we use, however, contain a larger number of lenses than this. The additional lenses are necessary to correct the *aberrations* of the optical system.

The surface of a lens is part of a sphere, because spherical surfaces are relatively easy to grind. Lens surfaces of non-spherical curvature are sometimes produced for special instruments, but such lenses are far too expensive to use in mass production. Every lens in a commercial optical instrument therefore has either two spherical surfaces, or one spherical and one plane surface. But light, in passing through a spherical surface, does not behave in an ideal manner. No single lens can actually converge parallel rays to a single point. These departures from ideal performance are called *aberrations.* Although a number of aberrations must be dealt with in the design of any optical instrument, two examples are sufficient to illustrate the problem.

White light is a mixture of colors. As previously stated, the angle of refraction at an optical surface depends on two factors: the angle of incidence and the index of refraction. But the index of refraction of any medium, such as glass, depends on the color of light. Blue light, for example, will be much more strongly bent than red light. (A familiar example of this can be seen in a prism, which will disperse a beam of white sunlight into a spectrum.) A lens will behave in the same way. Blue rays will be bent to a focus closer to the lens than the red rays. Because of this *chromatic aberration,* a lens will form a separate image for each color, and no two of these images lie in the same plane. As a result, the observer sees a fuzzy, indistinct image.

When parallel rays strike a spherical lens surface, those rays nearest the edge of the lens will be bent to a focus nearer the lens than rays striking the lens near its center. This effect is called *spherical aberration.* Because of spherical aberration, each zone of the lens produces a separate image, and no two of these images lie in the same plane.

It is not necessary, in this text, to explain in detail how aberrations are corrected. The optical designer has several variables to work with: the radius of curvature at each surface, the distance between surfaces, and the index of refraction of various kinds of glass. By a suitable manipulation of these variables, the designer is able to make the aberrations of one part of the optical system cancel those of another part, so that the system as a whole can produce an image of useful sharpness.

As a result, optical instruments are complex, and the spacing of the various elements must be maintained precisely. In a "simple" telescope, the objective consists of two or three separate lenses, often cemented together. The erector and ocular are each made up of from two to four separate lenses.

E. Types of Optical Equipment

16E1. Gun-sight telescopes

A *gun-sight telescope* provides the observer with an enlarged image of the target and thereby makes the target easier to see. At the same time, it establishes a line of sight from gun to target by presenting an image of the reticle crosslines superimposed on the target image.

A pair of telescopes is provided at each gun installation. One of these is used by the pointer, the other by the trainer. The trainer controls the train of the mount or turret, and the pointer controls the elevation of the guns, so that the crossline image in both telescopes is superimposed on the target image. Then, provided the axes of the telescopes have been previously adjusted to intersect the axis of the gun at that range, the axis of the gun bore will be aimed directly at the target.

However, unless the target is at point-blank range, the gun will not be fired with its axis pointing along the line of sight. The gun must be elevated above the line of sight, because of the curved trajectory of the projectile. The gun must usually be deflected laterally from the line of sight because of wind, projectile drift, and relative motion of gun and target. The necessary elevation and deflection angles are computed by the director. When this information is fed into the sight-adjusting mechanism, the optical axis of the telescope is moved until it diverges from the axis of the gun bore by the required angle. This may be accomplished in any of three ways: by moving the telescope itself, by turning one or more mirrors or prisms inside the telescope, or by a combination of these methods. Then, when the crosslines are superimposed on the target image, the gun will have the deflection and elevation necessary to hit the target.

Turret sight telescopes include all the gun-sight telescopes used in the turrets of battleships, and in the turrets and single-purpose main-battery mounts of cruisers. The optical system may be either of two general types: direct or indirect. Figure 16E1 is a diagram of the direct optical system. The optical axis of the telescope lies along the line of sight, and the sight mechanism provides the elevation and deflection angles by moving the whole telescope.

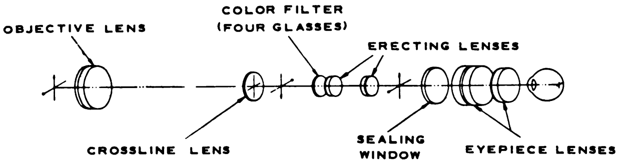

FIGURE 16E1.—Direct optical system.

The objective lens forms an inverted real image of the target. This image falls on the engraved surface of the crossline lens, or reticle. Between the reticle and the erecting lenses are the four color filters. (Only three of these are actually colored; the other is plain glass.) These filters are so mounted that the operator can bring any one of them into the line of sight. A filter of the proper color will, under some conditions, increase the contrast of the target image, and decrease the glare from sky and water. The erecting lenses erect the target image, and form a real image of the crosslines superimposed on that of the target. This second real image lies near the eyepiece, or ocular group. The sealing window is of plain glass. It makes it possible to seal the main part of the telescope, to keep out dirt and moisture. The eyepiece may be moved back and forth, to bring the image into focus, without affecting the seal of the rest of the instrument.

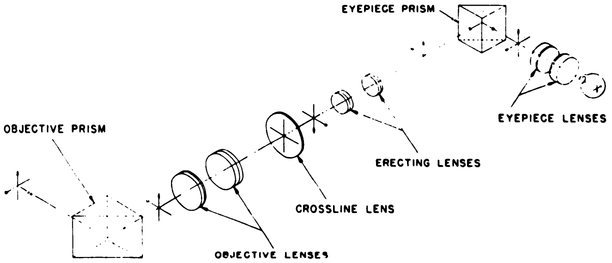

FIGURE 16E2.—Indirect optical system.

The indirect optical system, shown in figure 16E2, is basically similar to the direct system. The principal difference is that the line of sight is twice reflected by prisms, so that the axis of the telescope lies at right angles to the line of sight from gun to target. Figure 16E2 shows two separate objective lenses, which together form the first real image. Although this is true in some telescopes, the objective usually consists

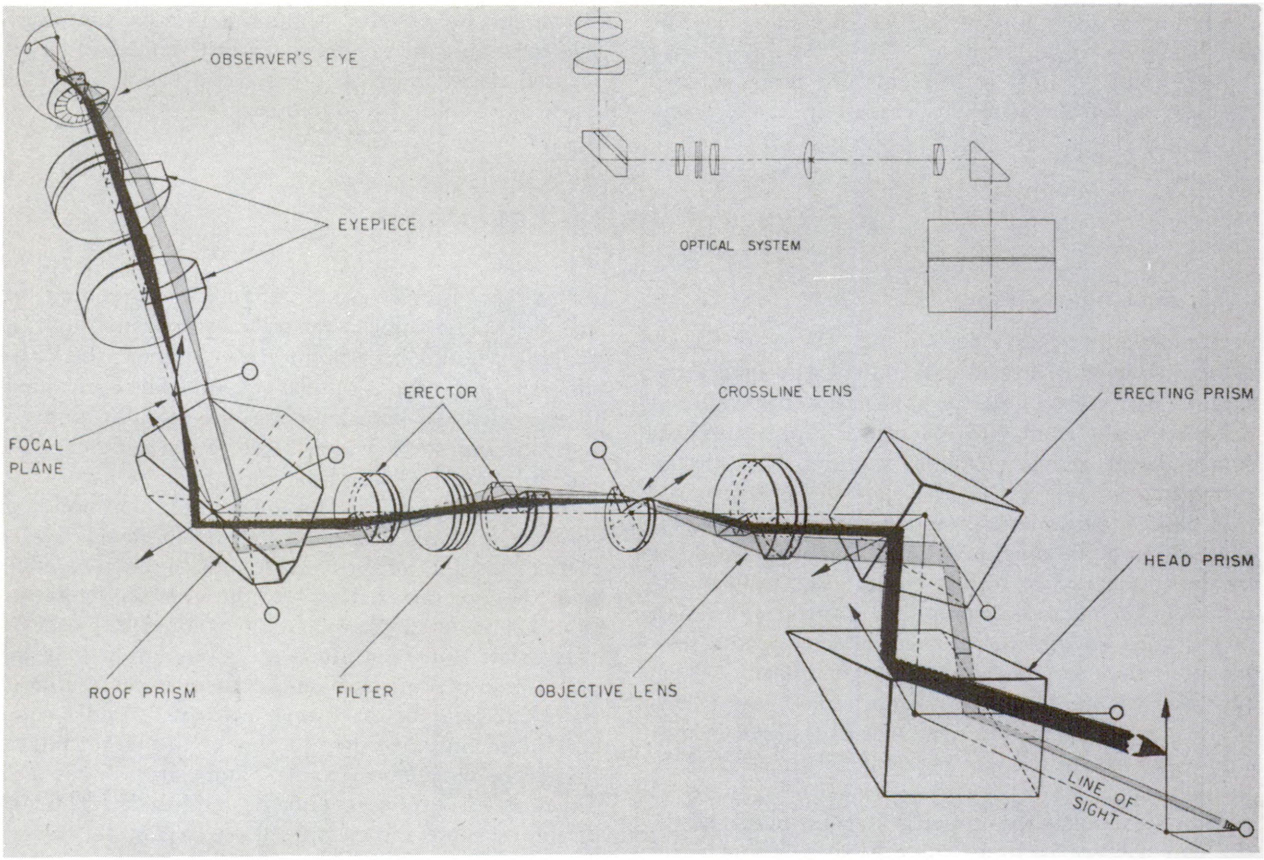

Figure 16E3.—Optical system of Telescope Mark 67.

of two lenses cemented together. The sealing window in this type of telescope is located between the eyepiece prism and the eyepiece lens group. The color filters are usually attached to the eyepiece mount, outside the sealed part of the instrument.

A telescope of this type may be mounted with its main axis either vertical or horizontal. When the telescope is horizontal, the sight mechanism controls the deflection angle by rotating the objective prism on a vertical axis. It controls the elevation angle by rotating the whole telescope on its long axis. When the instrument is mounted vertically, these functions are, of course, reversed. Because telescopes with the indirect type of optical system are often mounted vertically, they are usually called *turret periscopes.*

Antiaircraft gun-mount telescopes differ from turret telescopes in that the observer's line of sight through the eyepiece is not parallel to the line of sight from gun to target. If the target is in the same horizontal plane as the telescope, the observer must look *downward* into the eyepiece in order to see the target image. This feature makes it easier to track an overhead target without discomfort.

Figure 16E3 represents the optical system of a typical antiaircraft gun-mount telescope, the Mark 67. Light from the target is reflected first in the head prism, and then in the erecting prism, before it enters the objective lens. (The erecting prism is misnamed; it is used to bend the line of sight, not to erect the image.) The roof prism turns the line of sight back toward the observer, and at the same time bends it upward through an angle of about 35 degrees. The sight-setting mechanism controls the position of both the head prism and the erecting prism. The head prism rotates on a horizontal axis, to control the elevation of the line of sight. The erecting prism controls deflection of the line of sight by turning on an axis at right angles to that of the head prism.

16E2. Lead-computing sights

Lead-computing sights are used with automatic guns to provide a solution to the short-range antiaircraft fire control problem. The sight, like the gun-sight telescope, establishes a line of sight to the target. The gun axis is elevated at the necessary angle above the line of sight when the proper range inputs are made to the sight mechanism.

The short-range antiaircraft problem is more complex than the long-range antiaircraft and surface fire control problems. Unless the attacking aircraft is flying directly toward the gun, the elevation and deflection of the line of sight will change rapidly as the target approaches. Because of its high speed, the target may move a considerable distance while the projectile is in flight. The gun must therefore be aimed ahead of the target, if target and projectile are to reach the same point at the same time. In other words, the gun axis must lead the line of sight by the proper angle in both elevation and deflection. The more rapidly the line of sight changes in elevation or deflection, the greater the lead angle must be.

As its name implies, the lead-computing sight computes the necessary lead angle. The operator turns and elevates the sight to track the target. When he tracks successfully, the reticle image will appear to be superimposed on the target at all times. The sight, through the gun director, positions the guns so that the gun axis remains parallel to the axis of the sight. The sight mechanism, however, causes the operator's line of sight to lag behind the axis of the instrument. The more rapidly the sight is moved, the greater this lag will be. Since the operator uses this lagging line of sight to track the target, the axis of the sight, and therefore the axis of the gun, will lead the target by an angle proportional to the rate at which the sight is moved.

The lead-computing sight mechanism is based on one or more rapidly spinning gyroscopes. The principles of the gyroscope have been explained elsewhere in this text, in the chapter on torpedoes. It should be remembered that, when the axis of a spinning gyroscope is changed, the gyro will undergo precession, and move its axis in a direction at right angles to that of the applied force. In a torpedo, the gyro is free to move in any direction relative to its mount. In the lead-computing sight, the gyro movement is restrained, either by springs or by an electromagnet. When the sight is turned or elevated, thus tending to change the direction of the gyro axis, the gyro tends to undergo precession. The force it exerts on its restraining mechanism will be proportional to the rate at which the direction of its axis is changed. The sight mechanism applies this force to the optical system of the sight, in such a way that the line of sight lags by the proper angle.

Figure 16E4 represents the optical system of a lead-computing sight using a single gyro. The two windows seal the instrument to keep out dust and moisture. The system does not magnify the target image.

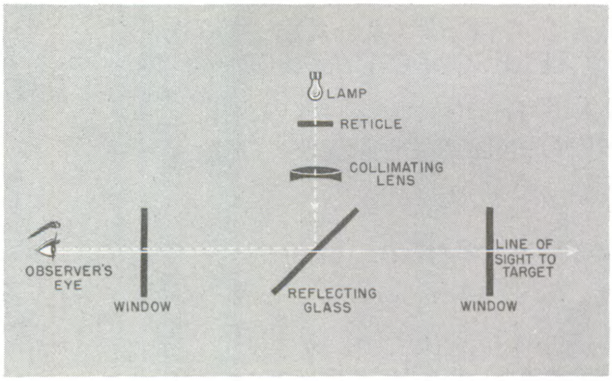

FIGURE 16E4.—Typical optical system of a single-gyro lead-computing sight.

The operator observes the target directly, through the two windows and the clear reflecting glass. The lamp at the top of the diagram is used to illuminate the reticle. The reticle is located exactly at the focal point of the collimating lens. Rays of light from the reticle are therefore parallel after they pass through the lens, and after they are reflected toward the operator by the reflecting glass. Because these rays are parallel, the reticle image appears to lie at infinity, and the reticle will not change its apparent direction when the operator moves his head from side to side.

The force of precession exerted by the gyro controls the angle of the reflecting glass. Although the angle of this glass has no effect on the line of sight to the target, it determines the apparent position of the reticle. Assume that the sight is trained to track a target moving across the field of view. The force exerted by the gyro will turn the reflecting glass, so that the reticle image tends to lag behind the target. In order to keep the reticle image superimposed on the target, the operator must make the sight axis lead the line of sight to the target. When the sight is elevated to track a target passing overhead, the gyro will tilt the reflecting glass so that the reticle image tends to lag below the target. Again the operator must lead the target in order to track it.

Most often, the line of sight to the target will be changing in both deflection and elevation. Then, when the target is tracked, the gyro will turn and tilt the reflecting glass at the same time. Thus the lead angle generated by the sight mechanism will be correct in both magnitude and direction.

Figure 16E5 is a diagram of the optical system of a lead-computing sight with two gyros. The line of sight from the target is reflected by each of four mirrors. The two lead-angle mirrors are controlled by the two gyros, so that the optical line of sight lags be-

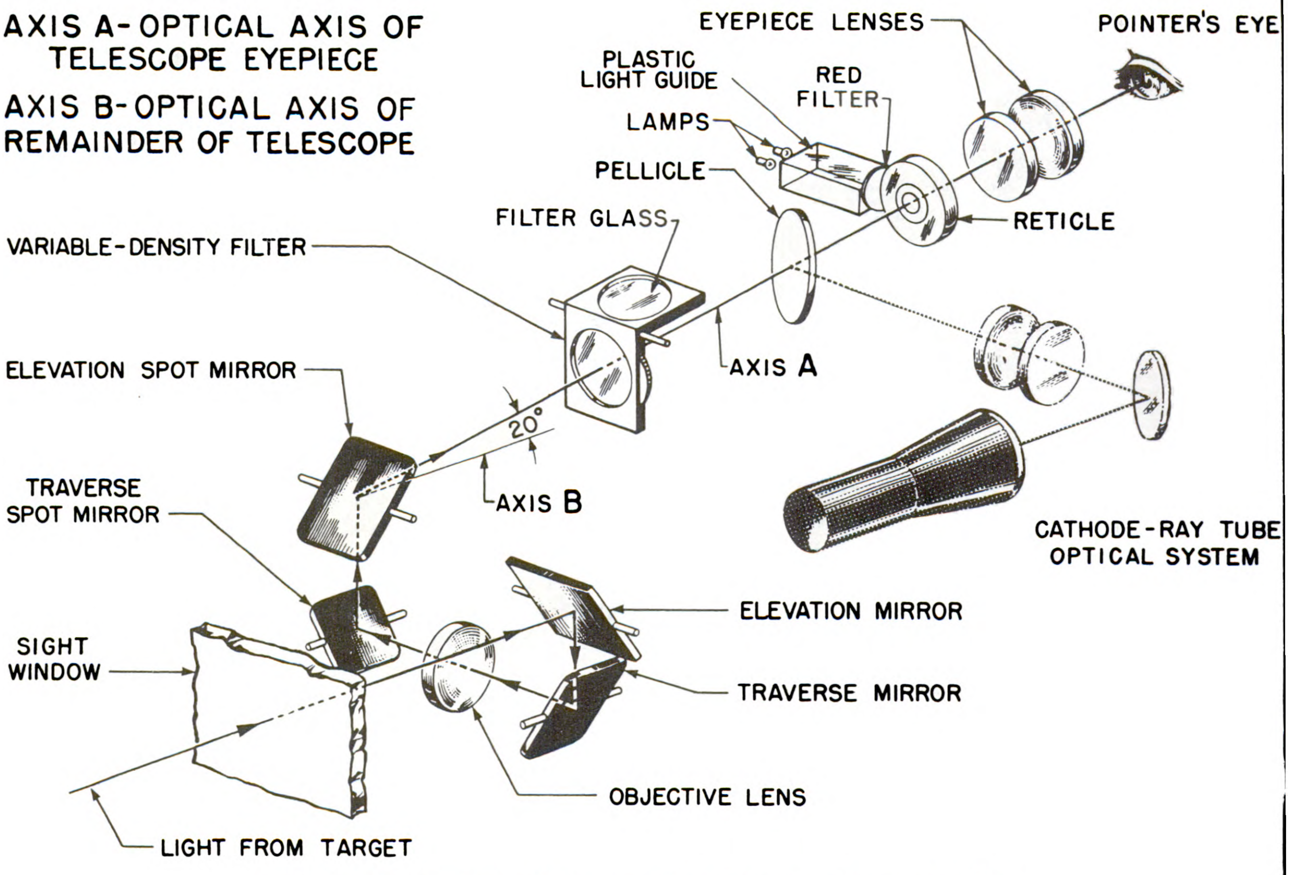

FIGURE 16E5.—Typical optical system of a two-gyro lead-computing sight.

hind the sight axis when the sight is moved. The two spotting mirrors are used only to adjust the line of sight during boresighting (see article 16E3). The objective forms a real image of the target, in the plane of the reticle. Target image and reticle are examined through the eyepiece. The system provides an enlarged erect image of the target. Since the image is inverted by reflection from the four mirror surfaces, no erector lens is necessary.

The filter bracket holds a pair of polaroid filters. One of these is stationary, and serves to decrease the glare from sky and water. The other polaroid filter may be rotated. Its degree of rotation, relative to the first filter, controls the image brightness. When the polaroid filters are not needed, they may be swung out of the line of sight. They are then replaced by a compensating glass, which has the same effect on image position as the two filters.

The pellicle is a plastic disc, coated with a thin, semitransparent film of aluminum. It has no effect on the target image, except to decrease its brightness somewhat.

The cathode-ray tube is used when the target is tracked by radar, rather than visually. The target "image" formed by the radar appears as a spot on the face of the cathode-ray tube. The light from this spot is reflected by the cathode-ray mirror, and passes through the cathode-ray objective lens. It is then reflected by the aluminum film on the pellicle, back toward the eyepiece. The objective forms an image of the spot in the plane of the reticle. When the axis of the radar antenna is pointed directly at the target, the spot appears to be centered in the reticle. When the target moves off the radar axis, the spot moves toward the side of the tube. The sight operator tracks the target by keeping the spot centered on the reticle. The lead angle generated by the sight controls the angle by which the guns lead the radar axis.

16E3. Boresight telescope

When the sight-setting mechanism is set for zero elevation and zero deflection, the lines of sight through the gun-sight telescopes must intersect the axis of the gun bore at the target. The boresighting operation is used to check this adjustment. One observer is stationed at each telescope, and one at the gun breech.

All observers sight on the same target; if the three lines of sight are observed to be on target at the same time, the gun is correctly boresighted. The lines of sight through the telescopes are, of course, established by the crosslines on their reticles. The boresighting equipment provides a line of sight through the gun bore.

Boresighting equipment is of several kinds. For the very small guns, such as the 20-mm antiaircraft guns, it consists of a breech attachment containing a peep hole, and a muzzle attachment with crosslines. The gun axis is aimed at the target by using the peep hole and crosslines as an open sight. The larger case guns may use a boresight with self-contained optics. This equipment converts the whole gun into a telescope. The muzzle fitting contains the objective lens; the breech fitting contains the reticle and eyepiece.

The 5″/38 and all bag guns may use a breech bar and boresight telescope. Figure 16E6 shows how this equipment is mounted. The breech bar is secured by screws to two threaded holes in the breech. The telescope housing is screwed into the breech bar, and locked rigidly in place by turning the locking ring up against the breech bar. The telescope is secured in its housing by a spherical bearing and four adjusting screws.

The telescope has a simple, straight-line optical system, consisting of objective, reticle, erecting lenses, and eyepiece lenses. The position of the objective may be adjusted, to bring the image into focus on the reticle, by turning the parallax-adjusting ring. The muzzle disc fits into the muzzle of the gun; the hole in the center of the disc lies on the axis of the gun bore.

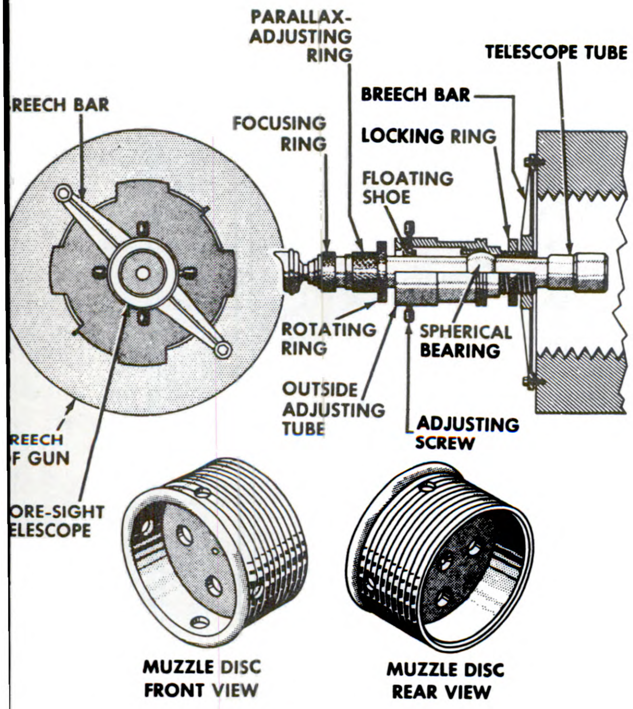

FIGURE 16E6.—Boresighting equipment.

To use the telescope, the operator turns the parallax-adjusting ring to bring the hole of the muzzle disc into sharp focus. The crosslines of the reticle should then intersect in the center of the hole. If they do not, the position of the telescope is changed by turning the adjusting screws. When the crosslines intersect at the center of the muzzle disc, the accuracy of the adjustment may be checked by rotating the telescope on its spherical bearing. The crosslines intersection should remain centered throughout 360 degrees of rotation. The muzzle disc is then removed from the gun, and the objective is adjusted to bring the target image into focus. When the reticle crosslines are superimposed on the target image, the target lies on the axis of the gun.

16E4. Rangefinders

The rangefinder consists essentially of a system of optical units assembled in a long, cylindrical tube. The tube is supported by a mount which permits training the rangefinder on the target. Early forms of mounts were little more than simple tripods. But modern rangefinders are generally supported on mounts integral with turrets or director housings, leaving only the protruding ends exposed. On its forward surface, the tube has a window at each end. Through these windows, the operator establishes two separate lines of sight to the target.

The rangefinder determines range by solving a right

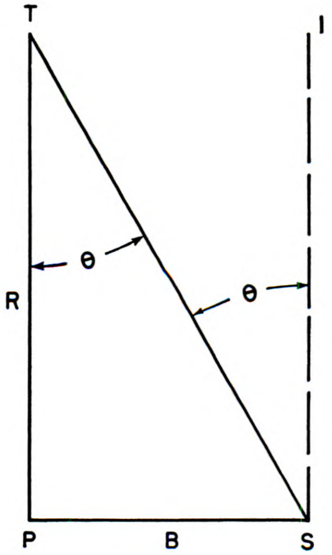

FIGURE 16E7.—The range triangle.

triangle in which one side and two angles are known. Range is one of the unknown sides. In figure 16E7, *TPS* is the range triangle. The line *PS* is the base length, *B*, is of the rangefinder. The target lies at *T*; line *PT* is the target range, *R*. The instrument is so constructed that angle *TPS* is always a right angle; in other words, the line of sight from the left end window is at a right angle to the axis of the rangefinder tube. The two lines of sight converge and meet at the target, forming the angle of convergence, θ. The angle of convergence is sometimes called the parallatic angle. The broken line *SI* is an imaginary line parallel to the range line *PT*. Angle *TSI* is therefore equal to the angle of convergence, θ. The rangefinder measures the angle of convergence by measuring the angle *TSI*.

In the range triangle, figure 16E7, angle *TPS* is always 90 degrees. Because this is a right triangle, it is apparent that $R=B \cot \theta$. In any given rangefinder, the base length *B* is always a fixed distance. The equation may be solved for *R*, then, as soon as the angle of convergence has been measured.

The rangefinder measures the angle θ by use of optical elements that deviate the line of sight from point *S* through a variable angle. The movable elements are connected to a suitably calibrated scale. The position of the scale depends on the angle through which the line of sight from *S* has been deviated. The scale is calibrated in accordance with the relation $R=B \cot \theta$. The range may therefore be read directly from the scale when the lines of sight from *P* and *S* intersect at the target.

There are two basic methods by which the operator can determine when the two lines of sight intersect at the target. These methods give rise to the names of the two types of rangefinders used by the Navy: the *stereoscopic* rangefinder and the *coincidence* rangefinder. With a coincidence rangefinder, the operator uses only one eye, and examines the two target images through a single eyepiece. The two lines of sight intersect at the target when the two target images appear to coincide. With the stereoscopic rangefinder, the operator uses both eyes; he examines the separate target images through separate eyepieces. The operator's eyes fuse the two images into a single image, as they do when observing the two images formed by a pair of binoculars. In each line of sight is a reticle, and the two reticle images are also fused into a single image. The operator adjusts the line of sight until the reticle image appears to lie at the same distance as the target image. The rangefinder has then measured the angle θ, and its scale indicates the range.

The theoretical requirements for a coincidence rangefinder are very simple. It must present magnified images of the target, so that coincidence of the two images may be accurately established. It therefore uses a telescope in each line of sight. The two lines of sight must point toward the target from the two ends of the rangefinder. They must, however, come together at the center of the instrument, so that both may be seen by a single observer. Each line of sight is therefore reflected twice: once at the end and once at the center of the rangefinder.

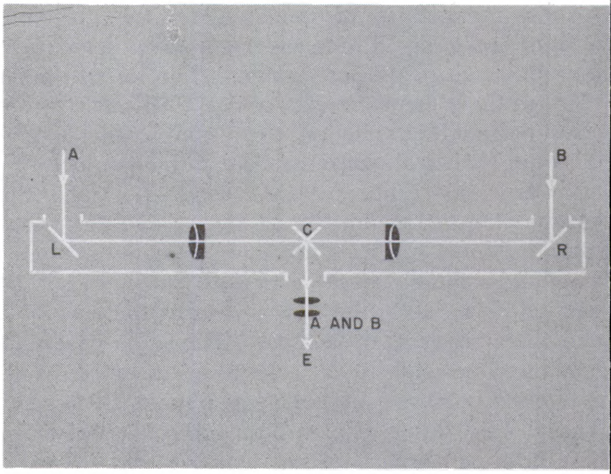

FIGURE 16E8.—Simple coincidence rangefinder.

In figure 16E8, *A* and *B* represent the two lines of sight to the target. Assume for the moment that the target is at an infinite distance, so that *A* and *B* are parallel. *L* and *R* are mirrors, each mounted at an angle of 45 degrees to the tube axis. Each line of sight will therefore be reflected through 90 degrees. After reflection, each line of sight passes through a telescope objective lens. *C* represents two 45-degree mirrors, one above the other. Each line of sight will be reflected through 90 degrees by one of these mirrors. After the second reflection, the two lines of sight will coincide. The two images may be seen by the observer, at *E*, through a single eyepiece.

When the two lines of sight coincide, as in figure 16E8, the observer sees a single, unbroken image of the target. Actually, this image consists of two half images, one above the other. One of these half images will be formed by light reflected from *L*, the other by light reflected from *R*.

Part A of figure 16E9 shows a slight improvement on the optical system of figure 16E8. The two mirrors at *L* and *R* have been replaced by pentaprisms. In these prisms, the line of sight is reflected twice. The images are therefore not reversed from left to right, as they would be by single mirrors. The pentaprisms cannot depend on total internal reflection, since light strikes both reflecting surfaces at less than the critical angle; these surfaces are therefore silvered. Penta-

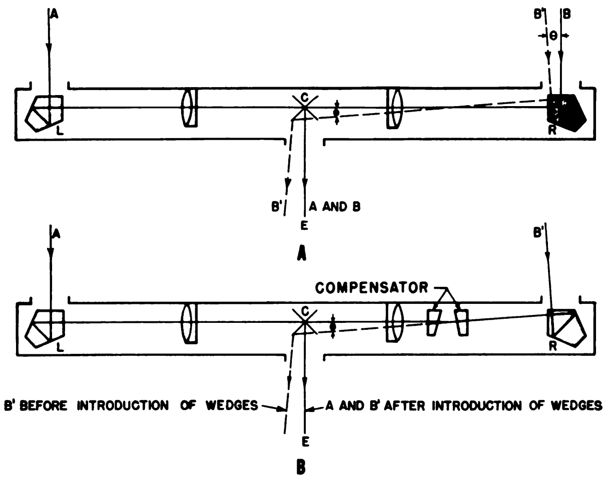
A
B'
B
θ
C
L
R
B'
A AND B
E
A
A
B'
COMPENSATOR
C
L
R
B' BEFORE INTRODUCTION OF WEDGES
A AND B' AFTER INTRODUCTION OF WEDGES
E
B

Figure 16E9.—Coincidence rangefinder principle.

prisms are used only in relatively small rangefinders. The largest rangefinders in service would require pentaprisms of prohibitive size. In these instruments, two mirrors are substituted for each pentaprism, with their surfaces in the same relative position as the two reflecting surfaces of the pentaprism.

If the target is not at infinity, the two lines of sight will not be parallel, and they will not coincide at *E*. (For simplicity, the eyepiece has been omitted in figure 16E9.) The broken line *B'* represents the line of sight from a target at medium range. This line diverges from *B* by the angle of convergence, *θ*. The target image, as seen by the observer, will be broken in the center by a horizontal line; the upper half of the image will be displaced with respect to the lower. (The observer customarily ranges on some *vertical* line on the target, so that any displacement of the upper image can be easily detected.)

The operator can measure the angle of convergence, and therefore the range, by turning the line of sight *B'* through the angle *θ*. There are several ways in which this could be done; for example, by rotating the pentaprism at *R* on a vertical axis. This system, however, has an obvious disadvantage. The angle of convergence is always very small. Assume, for example, that the base length of the rangefinder is 20 feet. If the target range changes from 1,000 yards to 50,000 yards, the angle of convergence will change by approximately half of one degree. If the pentaprism is rotated, it will deviate the line of sight by *twice* the angle of rotation. The rangefinder would be changed from minimum to maximum range by only one quarter of a degree of adjustment. Even with reduction gearing between the range scale and the prism, the scale would be too crowded to be useful.

Part B of figure 16E9 represents the system actually used. Two thin prisms or wedges, comprising the *compensator,* have been inserted in the *B'* line of sight. A prism, it will be remembered, deviates light toward its base. If the two wedges deviate *B'* through the angle of convergence, the two lines of sight will then coincide, and the target image will appear unbroken. The compensator is so constructed that the angle of deviation is continuously variable. This is accomplished by rotating the two wedges through equal angles, in opposite directions.

Figure 16E10 shows how this system works. If it is remembered that a prism always deviates light toward its base, the figure is self-explanatory. As the diagrams show, the wedges must be rotated through an angle of 90 degrees to change the deviation from minimum to maximum. This makes possible the use of a long, uncrowded range scale.

The optical system of an actual rangefinder is somewhat more complex than that shown in figure 16E8, although it will not be described in detail here. The rangefinder includes a supplementary optical system for use in calibration. It also has a halving adjustment, by which the two images can be adjusted so that there is no overlapping or duplication. The astigmatizer, which may be inserted in the line of sight when necessary, distorts the image so that the image of a point appears as a vertical line. This makes it possible to use a coincidence rangefinder to range on a searchlight at night. And the rangefinder does not use two simple mirrors to reflect the images toward the observer, as shown at *C* in figures 16E8 and 16E9. It uses a coincidence prism for this purpose.

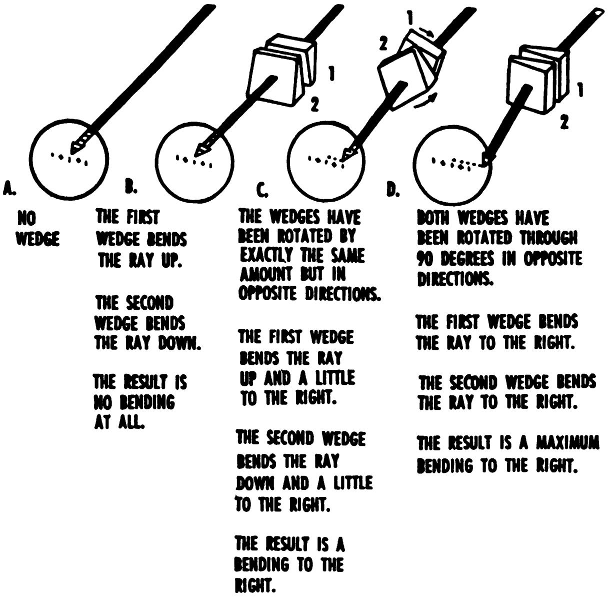
1
2
1
2
1
2
1
2
A.
NO WEDGE
B.
THE FIRST WEDGE BENDS THE RAY UP.
THE SECOND WEDGE BENDS THE RAY DOWN.
THE RESULT IS NO BENDING AT ALL.
C.
THE WEDGES HAVE BEEN ROTATED BY EXACTLY THE SAME AMOUNT BUT IN OPPOSITE DIRECTIONS.
THE FIRST WEDGE BENDS THE RAY UP AND A LITTLE TO THE RIGHT.
THE SECOND WEDGE BENDS THE RAY DOWN AND A LITTLE TO THE RIGHT.
THE RESULT IS A BENDING TO THE RIGHT.
D.
BOTH WEDGES HAVE BEEN ROTATED THROUGH 90 DEGREES IN OPPOSITE DIRECTIONS.
THE FIRST WEDGE BENDS THE RAY TO THE RIGHT.
THE SECOND WEDGE BENDS THE RAY TO THE RIGHT.
THE RESULT IS A MAXIMUM BENDING TO THE RIGHT.

Figure 16E10.—Deviation of light by two compensator wedges.

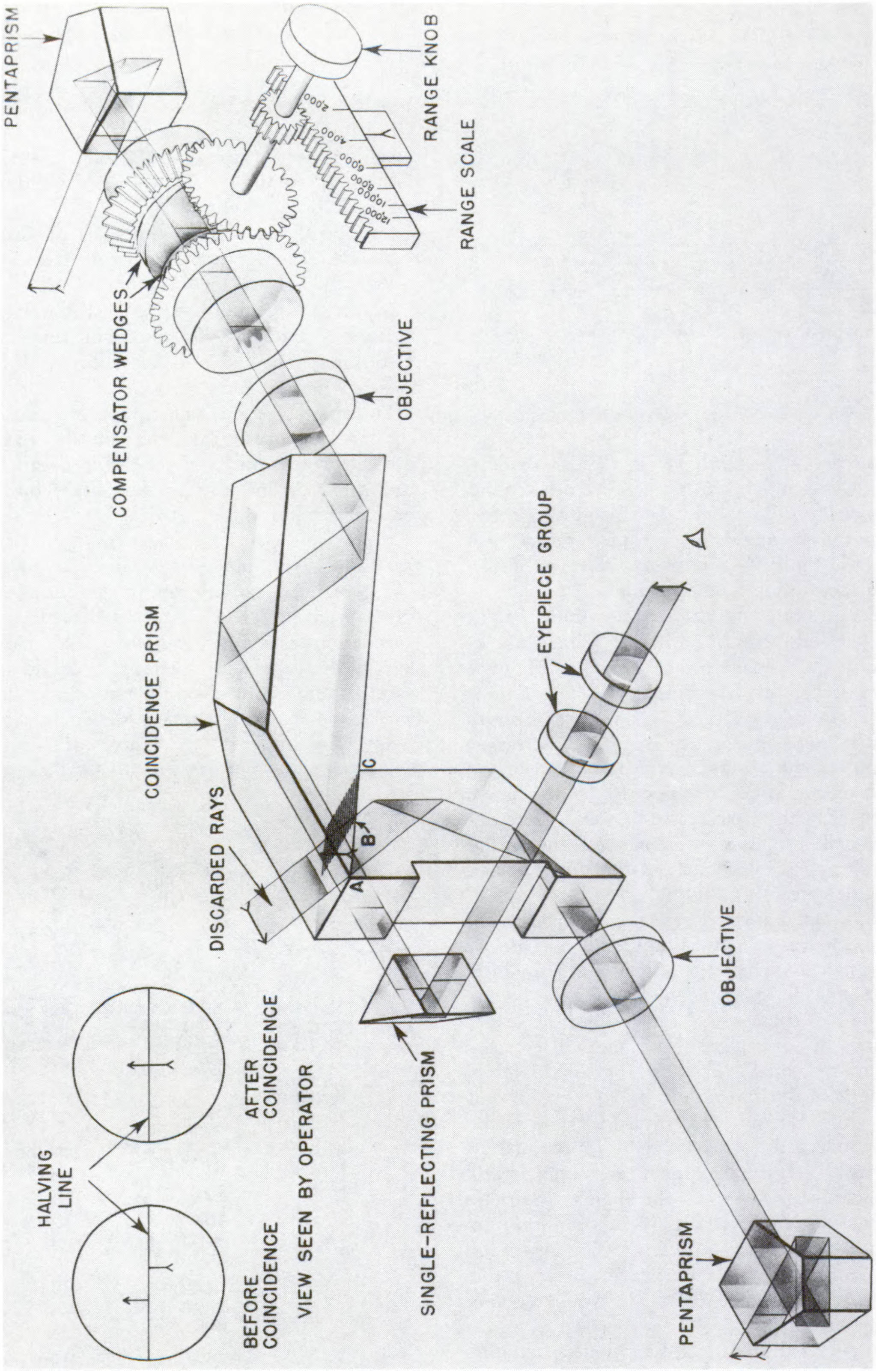

Figure 16E11.—An elementary coincidence rangefinder.

Figure 16E11 is a simplified diagram of a coincidence rangefinder, showing the coincidence prism. This prism is rather complex, and difficult to represent in a two-dimensional drawing. It consists of three separate prisms. The two larger prisms are cemented together. Half of the cemented area, represented by shading at *B* and *C,* is silvered.

Light from the left pentaprism is reflected twice in the large vertical element of the coincidence prism group. Half of this light—the part that forms the lower half of the image—then strikes the silvered surface and is reflected toward the single reflecting prism. The rest, forming the upper half of the image, misses the silvered surface; it passes out through the top of the prism, and is discarded.

Light from the right pentaprism, after deviation by the compensator wedges, is reflected upward at the lower face of the diagonal prism. It is reflected again at the roof-shaped upper faces. The part of this light that forms the lower half of the image strikes the silvered surface, where it is reflected upward and discarded. The rest, forming the upper half of the image, continues on to the single reflecting prism. The single reflecting prism reflects both halves of the image toward the eyepiece.

The coincidence prism group reflects each half of the image without reversing it from left to right, as single mirrors or prisms would. In addition, it inverts the image. Therefore no erector lens is needed in a coincidence rangefinder.

The use of a *stereoscopic* rangefinder depends on the stereoscopic vision of the operator. "Stereoscopy" has the literal meaning of its Greek roots: *seeing solid.* Stereoscopic vision makes it possible to see objects as solid and three-dimensional, and to judge their relative distances. The appearance of solidity has no application in rangefinding. Operation of the stereoscopic rangefinder depends on judgment of relative distances.

The relative distance of two objects may be determined in any of several ways:

1. *Intervening objects.* When one object partially conceals another, the concealed object is obviously the more distant.

2. *Relative sizes.* If two objects known to be of equal size are at different distances from the eye, the more distant object will appear smaller.

3. *Aerial perspective.* The veiling effect of atmospheric haze usually increases with distance. If one of two objects appears hazier than the other, it is probably the more distant.

4. *Focusing.* The muscular effort required to focus the eye depends to some extent on the distance of the object focused on. This effect is useful only at short distances.

5. *Convergence.* If an object is to be seen sharply by both eyes, the two lines of sight, one from each eye, must intersect at the object. The angle of convergence depends on the distance of the object. A certain muscular effort is required to change the angle of convergence. This effort provides the observer with a basis for judging relative distances.

6. *Image doubling.* When the two lines of sight intersect at a given object, all objects nearer or farther will appear doubled. It will be shown below that nearer objects appear doubled in one way; farther objects appear doubled in an entirely different way.

Of the effects listed above, the first four are apparent even when one eye is closed. They are therefore not suitable for use in a stereoscopic rangefinder. The last two, however, require binocular vision—the use of both eyes at once. The stereoscopic rangefinder makes use of both these effects.

The human eye is a simple optical instrument. Refraction occurs at the *cornea,* or curved front surface of the eye, and at both surfaces of the *lens,* located a short distance behind the cornea. The lens and cornea, acting together, form a convergent lens system. They form a real inverted image of any object seen. This image falls on a sensitive layer, the *retina,* at the back of the eye. The nerves of the retina, when stimulated by light, carry impulses to the brain, where the image is interpreted.

One small spot on the retina is capable of perceiving a sharp image; the image on any other part of the retina is more or less blurred. The outward projection of this spot, through the optical center of the lens, is the line of sight. To see any point clearly with one eye, the observer must *fixate* that point. Fixation consists in turning the eye until the line of sight reaches the point observed; the image of that point then falls on the small sensitive spot of the retina. Binocular fixation of a point requires that the two lines of sight intersect at the point of fixation. Each eye then forms an image of that point on the sensitive spot. The small size of this spot may be demonstrated by fixation of a colon (:). Either dot of the colon may be fixated separately; shifting from one to the other requires a detectable muscular effort.

In judging the relative distance of two nearby objects, the observer customarily uses his two eyes as a simple coincidence rangefinder. The lines of sight from the two eyes correspond to the lines of sight from the two end windows of the rangefinder. The distance between the eyes corresponds to the rangefinder base length. When the two rangefinder images coincide, the range may be read on the scale; when the two eye images coincide, the distance may be estimated from the muscular effort required to secure coincidence.

To demonstrate this effect, hold the index finger of one hand vertically, at arm's length in front of the face. Hold the index finger of the other hand vertically in front of the face, at a shorter distance. Now shift fixation from one finger to the other, and note the muscular effort required to change the angle of convergence. Note also that when either finger is fixated, the other appears doubled. When one finger is fixated, the fact that the other appears doubled shows that it lies at a different distance; the *way* in which it is doubled shows whether it is nearer or farther than the one fixated. Figure 16E12 illustrates this point.

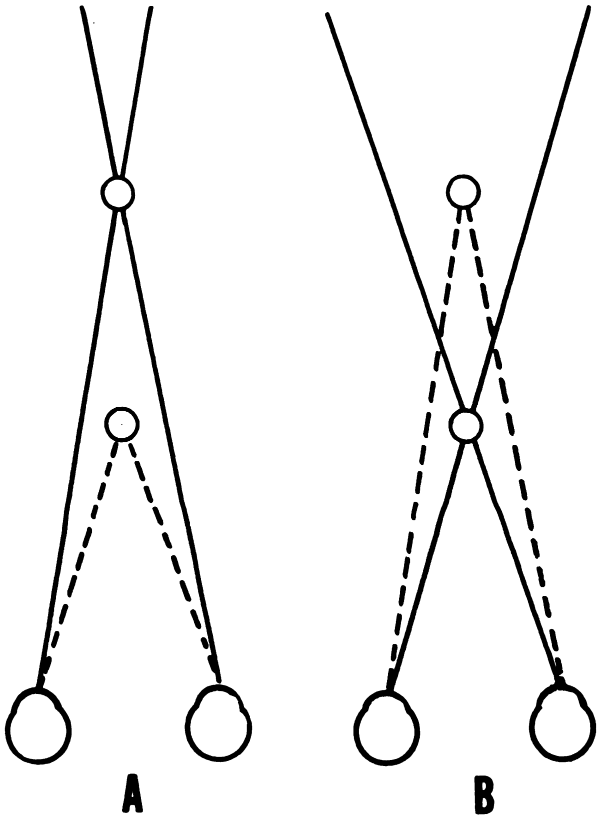

Figure 16E12.—Binocular fixation.

In both drawings, the solid lines represent the lines of sight to the point of fixation. The broken lines represent the path of light from the other finger to the eyes. In part A of the figure, the point of fixation is on the more distant finger; the other finger appears doubled. To the right eye, the near finger will appear to be at the *left* of the point of fixation. To the left eye, it will appear to be to the *right*. In part B of the figure, the near finger is the point of fixation. Now the right eye sees the other finger on the *right*, while the left eye sees it on the *left* of the point of fixation.

Because the manner of image doubling differs, it is possible, by fixating *either* finger, to judge which is the closer. By changing the fixation from one to the other, and thereby changing the angle of convergence, the original judgment may be confirmed.

However, the ability to judge relative distances is limited. If both objects are beyond the *radius of stereoscopic vision*—approximately 450 yards—the difference between their angles of convergence is too small to be detected. This distance is obviously too small to be useful in finding the range of a target. The stereoscopic rangefinder extends the observer's radius of stereoscopic vision by increasing the apparent angle of convergence of distant objects. It does this in two ways: first, it provides magnified images of the target; second, it increases the effective distance between the observer's eyes. The stereoscopic rangefinder, like the coincidence type, uses two telescopes, with their lines of sight extending toward the target from the two end windows. The telescopes provide magnified images of the target. And the effective distance between the observer's eyes is equal to the base length of the rangefinder.

The observer's eyes fuse the two target images, one from each telescope, into a single unbroken image, just as they do when observing the target through a pair of binoculars. In each telescope of the rangefinder is a reticle. The observer fuses the two reticle images into a single image. Figure 16E13 provides a simple exercise to show how this is possible.

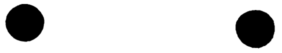

Figure 16E13.—Fused dots.

Hold a sheet of cardboard on edge, perpendicular to the paper, midway between the two dots. Place the head about 12 inches from the page, so that the eyes can look squarely at the paper as in reading. Adjust the cardboard so that each eye sees only one of the dots. Now, while looking at the dots, relax the eyes and try to look through the paper. After a short time the two dots will fuse into a single, blurred image. Without losing fusion, refocus the eyes until the two dots appear as a single, sharp image. This exercise is well worth while, even if it requires several minutes of patient effort.

Because the apparent angle of convergence of the

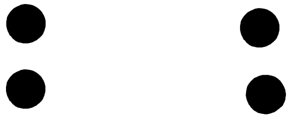

Figure 16E14.—Double fused dots.

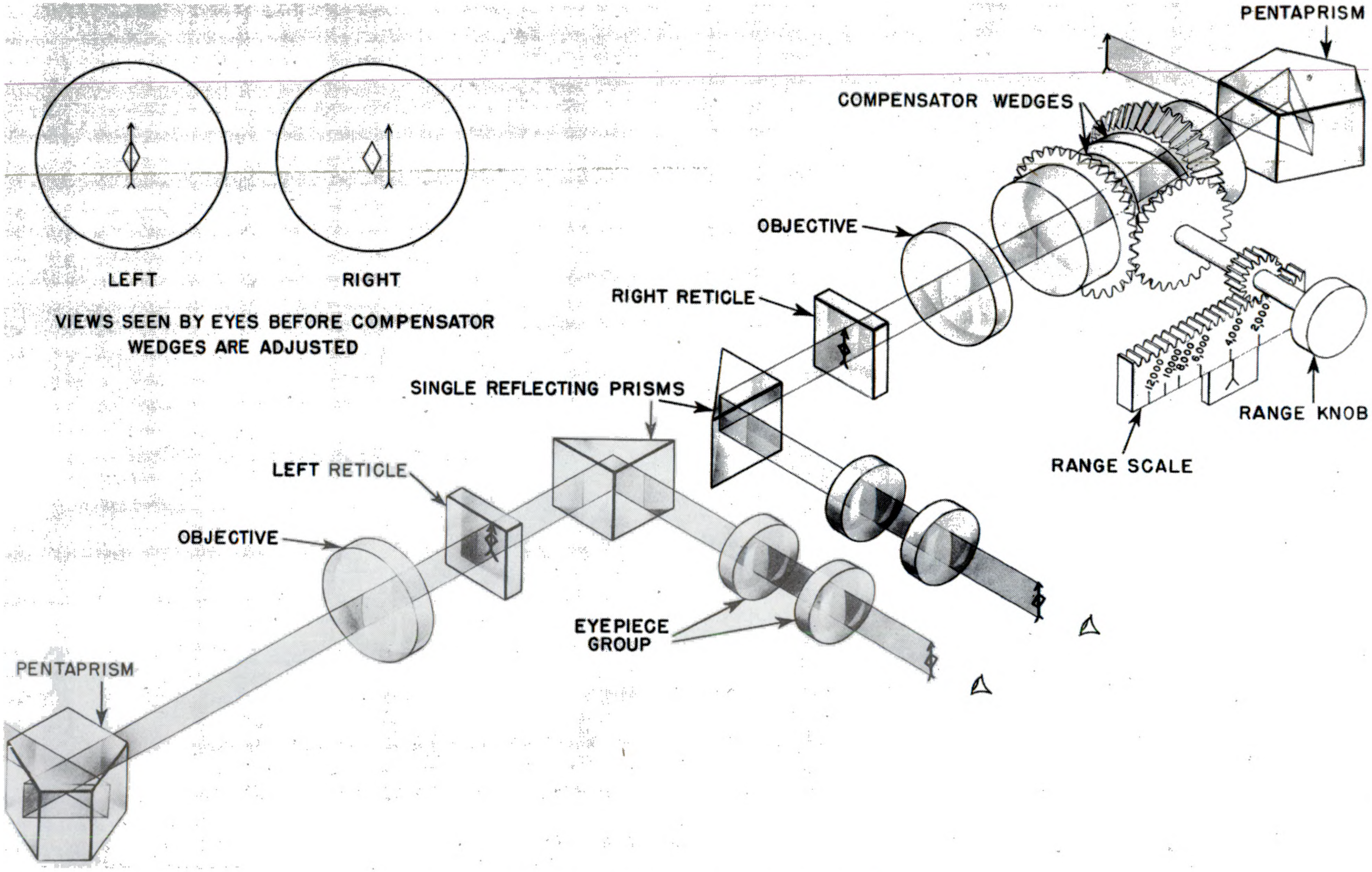

FIGURE 16E15.—An elementary stereoscopic rangefinder.

two reticles is fixed, the reticle pattern appears to lie at a certain fixed distance in space. If the target happens to be at that distance, target and reticle will appear to be equally distant from the observer. Assume for a moment that the target is at some other distance. The apparent angle of convergence of the target will differ from that of the reticle. The observer may fixate either target or reticle, but he must change convergence to from shift one to the other. And, when he fixates either, the other will appear doubled. The difference in convergence, and the way in which the image is doubled, show the observer which image is nearer.

Figure 16E14 will illustrate this effect. Use the sheet of cardboard, as with figure 16E13. Fuse the upper pair of dots, and bring them into sharp focus. Then change fusion to the lower pair of dots. Change back and forth several times. Because of the difference in convergence, and the consequent doubling of one pair of dots, the upper pair will appear to be closer.

As previously stated, the angle of convergence of the two reticles is fixed. The angle of convergence of the target may be changed, however, by adjusting the compensator wedges. To determine the target range, the operator adjusts the wedges until the target and reticle appear to lie at the same distance. He may then read the range on the calibrated scale.

Figure 16E15 is a simplified diagram of the optical system of a steroscopic rangefinder. (Each of the two telescopes contains an erector system, which has been omitted from the drawing for the sake of simplicity.) The two circles at the upper left show the views seen by the two eyes before adjustment of the compensator wedges. The diamonds represent the reticle pattern; the arrows represent the two images of the target. By using a piece of cardboard, it is possible to fuse these two views, although this takes more effort than fusing the dots in figure 16E14. The target arrow will appear to be considerably more distant than the reticle diamonds.

Figure 16E16 represents the image of reticles and target as actually seen through the eyepiece group. Note that the retitcle image consists of one row of diamonds and four rows of vertical lines. The center diamond is used for ranging on the target. All the marks in any one row appear to be at the same distance from the observer. The row of lines immediately above the diamonds appears to be more distant than the diamonds, and the top row appears to be still more distant. The row immediately under the diamonds appears to be nearer than the diamonds, and the bottom row appears to be nearer still. When the center diamond has been superimposed on the target, the rows of vertical lines make it possible to estimate the range of bursts or splashes without readjusting the compensator wedges. At any given range, the apparent distance between any two adjacent rows corresponds to a fixed distance. When this distance has

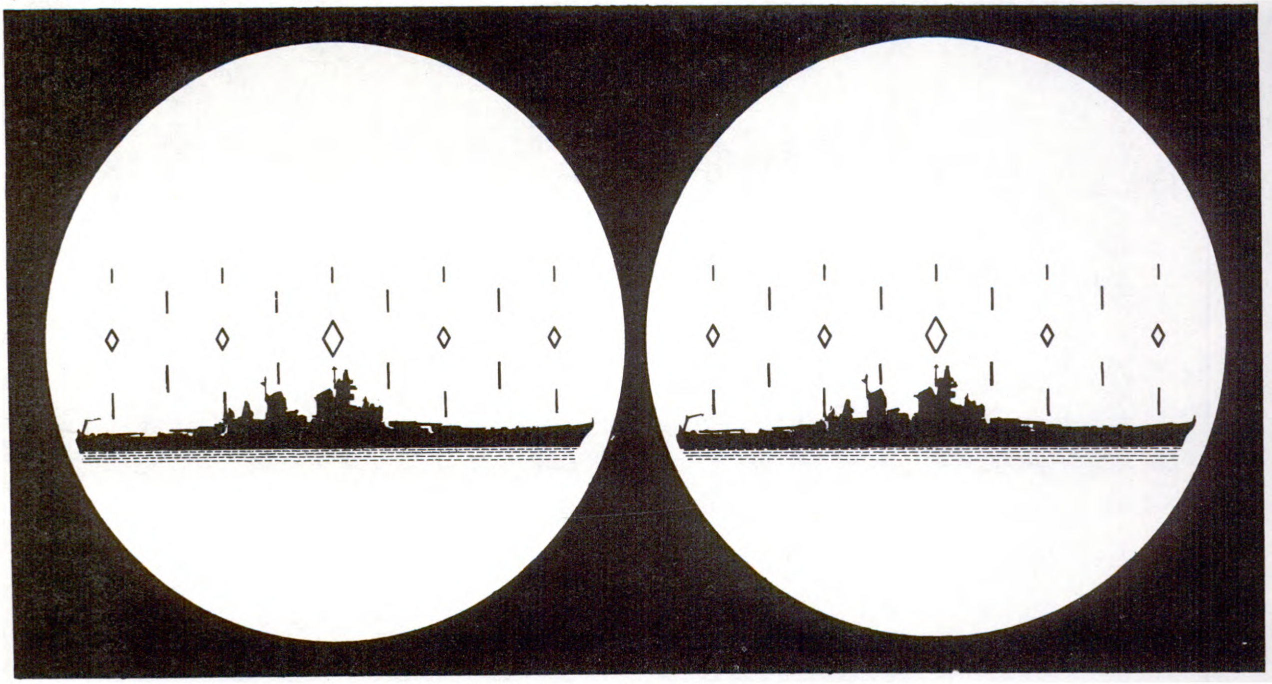

Figure 16E16.—Reticles and target as seen from eyepiece group.

been determined from a table, the necessary spot corrections can be quickly estimated.

The horizontal distance between any two adjacent marks in the same row corresponds to five mils in deflection. Thus deflection spots can be made without training the rangefinder off the target. Because it is more useful for spotting, as well as for ranging on fast-moving targets such as aircraft, the stereoscopic rangefinder is more widely used than the coincidence rangefinder.

F. Combat Information Center (CIC)

16F1. Mission and functions

The ship's combat information center (CIC) is the organization which processes tactical information. Its mission is to keep command and control stations informed of the tactical situation at all times. In general terms, this means that CIC (usually referred to as *Combat*) must maintain an up-to-date, comprehensive picture of the disposition of all friendly and enemy forces within range of the available intelligence. CIC must maintain the picture in a form which will permit rapid interpretation of each new bit of information, integration of new information with all other data, and immediate transmission of the new information with its significant implications to all who need it in the performance of their duties. Procedures employed by CIC in accomplishing its mission in any tactical situation are summarized in the titles of five routine functions:

Collection.
Display.
Evaluation.
Dissemination.
Control.

1. *Collection.* By means of internal and external communications systems, CIC collects tactical data from the following major sources:

a. Radar.
b. Sonar.
c. Radio.
d. Visual lookouts.
e. Publications (operation plans, orders, *etc.*).
f. ECM equipment.

2. *Display.* Data collected by CIC are displayed prominently on the following standard displays:

a. Summary plot. A comprehensive *relative* display of the positions and/or tracks of friendly, unidentified, and enemy forces, geographical points, and other data required to accomplish any tactical mission in which the ship or task group may be engaged.

b. Geographic plot (DRT). A *true* display of the positions and/or tracks of friendly, unidentified, and enemy surface and subsurface forces, geographical points, and other objects, moving or fixed.

c. Surface plot. A *relative* display of the positions and/or tracks of friendly, unidentified, and enemy surface and subsurface forces, and other objects, moving or fixed.

d. Disposition diagram. A *relative* display of all ships in a formation, showing all stations in the formation, axis and center, and the screen sector origin and center.

e. Status boards. A convenient and prominent display of tactical data. The size and purpose of status boards vary with different types of ships. Data displayed thereon will also vary.

f. Strategic plot. Displays of tactical and strategical information on navigational and grid charts. In general, charts are used for display of information which is beyond the range of the standard plots or which is of more permanent nature.

g. Air plot. Displays all air contacts, and includes information derived from own ship's radar or radio reports from other ships.

3. *Evaluation.* Evaluation (appraisal, determination of the tactical significance of information collected and displayed in CIC) is accomplished on two levels: (a) the routine application of the principles of dead reckoning (time, speed, distance, direction) and relative movement (the resultant of two or more relative motions) to all tactical data; (b) the broader integration of the information thus gained with all available knowledge and information of tactical or strategical value, and the arrival at a conclusion or decision.

4. *Dissemination.* Information which has been collected, displayed, and evaluated must be disseminated without delay to those who need it for proper performance of their duties. As a matter of routine, CIC keeps the following command and control stations informed:

a. Primary control (bridge, CO, tactical plot, *etc.*).
b. Weapon control (main battery, secondary batteries, torpedoes, depth charges, *etc.*).
c. Flag plot.
d. Officer in tactical command.
e. Airborne aircraft under control.

5. *Control.* Having collected, displayed, evaluated, and disseminated each new bit of information,

CIC may be directed by command to take action or to assume certain control functions.

a. These control functions usually are assumed in CIC in accordance with *doctrine:*

(1) Control of all search radars and passive electronic countermeasures equipment.

(2) Control of communications with other ships in the formation on inter-CIC radiotelephone nets. Also control of communications with airborne aircraft which are under own ship's control.

(3) Control of assigned airborne aircraft.

b. When *directed* by command, CIC will assume control in the following situations:

(1) Jamming on enemy radar frequencies.

(2) Interception of air contacts or raids by designated combat air patrol (CAP).

(3) Control of SFCP spotting nets.

(4) Control of torpedo firing under conditions of low visibility or torpedo director failure.

(5) Direction of the attacking ship in coordinated antisubmarine attacks, and of own ship in case of sonar failure.

(6) Control of the air phases of search and rescue, including control of communications with all units.

(7) Control of AA defense (own ship, unit, or force).

16F2. Personnel

Normally, all Radarmen and Radarman strikers are assigned to the CIC division for duty and for administrative purposes. The CIC division is a part of the operation department. The operations officer is the head of the department, and the CIC officer usually is the division officer.

Personnel requirements for each type of ship are based on the size of the ship, the functions for which the ship was designed, and the minimum number of positions to be manned during normal cruising on a continuous watch-standing basis.

Every member of the CIC team is trained to perform the duties and accept the responsibilities of each station in Combat. Personnel participate in formal training programs aboard ship and in team-training activities at fleet training centers. In addition, the men are rotated at the various positions during normal cruising watches to provide the broadest possible experience.

The key personnel in CIC are:

1. *Evaluator.* An officer experienced in tactics (normally the operations officer) acts as adviser to command. By his qualifications and experience, he is well versed in all matters pertaining to naval operations. He is kept informed of the general tactical situations in order to make the best evaluation of information available in CIC. The evaluator is charged with general supervision of the combat information center during general quarters.

2. *CIC officer.* Under the operations officer, he is charged primarily with the operation and maintenance of the combat information center and the equipment connected therewith. His duties include the collection and distribution of operational information, supervision of lookouts, maintenance of records, and preparation of reports.

3. *Controller.* This man is charged with the responsibility for controlling aircraft in the air-defense area. He is qualified to perform all CIC functions, and is particularly proficient in all phases of aircraft control. His other duties include assisting the CIC officer in evaluating the tactical situation, supervising CIC operations, and controlling communications used in interceptions under his control.

4. *CIC watch officer.* The CIC watch officer takes charge of the watch in Combat. He sees that CIC logs are properly maintained and that watch routine is observed. He is responsible for the performance of CIC during the period of his watch.

5. *Gunnery liaison officer.* An officer of the gunnery department responsible for passing target indication data from CIC to gunnery control stations is stationed in CIC. He is proficient in the interpretation of radar indications. His duties include effecting the transfer of targets from search radars to fire control radars, and relaying available radar spotting information to gunnery control stations. He must have a complete knowledge of the target designation and acquisition situation.

6. *Enlisted personnel.* Enlisted personnel positions in CIC are identified by the specific plot upon which a plotter is recording information, and by the specific radar or other equipment which the man is operating. The men are generally designated plotters, operators, talkers, or recorders.

16F3. Tactical application of functions

The effectiveness of CIC is determined by the proficiency with which it performs the five routine functions in naval tactical operations. CIC's contributions in such operations are discussed briefly below. In every case CIC collects, displays, evaluates, and disseminates information. Where CIC also has some measure of control of the operation, the extent of control is mentioned.

1. *Radar-assisted navigation.* In radar navigation, CIC plots the ship's track, obtains radar fixes, determines set and drift, keeps the bridge informed of all hazards, and makes recommendations for appropriate

courses and speeds. The geographic plot and navigational charts are used for this purpose.

2. *Formation and screen maneuvers.* In formation and screen maneuvers, CIC keeps a plot of all friendly forces, solves relative-movement problems for changing stations, and makes recommendations to the bridge for appropriate course and speed changes. CIC also tracks all unidentified contacts and keeps the bridge informed. The disposition diagram, the surface plot, and the geographic plot are the principal equipment used in tactical maneuvers.

3. *Gunnery coordination and liaison.* In gunnery liaison, CIC:

a. *Indicates* available targets by passing information on all contacts to command and gunnery control stations.

b. *Designates* specific targets to gunnery control stations as directed by command.

c. *Assists* gunnery control stations in *acquisition* of targets by using target-designating and internal communications systems to transfer *designated* targets from search radar to fire control radar tracking. In gunnery or AA coordination, CIC controls the special communication channels which are required. All standard displays in CIC provide information in gunnery coordination and liaison.

4. *Naval gunfire support.* CIC performs the same duties in naval gunfire support as in radar navigation, keeping the bridge informed and, in addition, supplying gunnery control stations and plot with data for fire control solutions—course, speed, set and drift, bearing and range to the target, location of front lines of own troops on shore, *etc.* The geographic plot and target-area designating grid charts are used for this purpose. Surface plot also is used for plotting unidentified contacts and keeping track of friendly forces.

CIC also *controls* communications with the observing party on shore, when directed.

5. *Torpedo attack control.* CIC solves relative movement problems, and makes recommendations to the bridge for approach and retiring courses and speeds. Having solved for base torpedo course and firing point, CIC is prepared to transmit pertinent information to torpedo control, if directed. The geographic plot and the surface plot are the principal equipment used in torpedo attack. The maneuvering board and other aids are used for precise solutions.

CIC normally provides supplementary information for torpedo attack. Under a radar-controlled attack, CIC exercises direct control, with instructions to torpedo control.

6. *Antisubmarine operations.* CIC uses both sonar and radar information continuously to track the submarine and other assisting or attacking ships. Combat keeps the bridge, underwater battery plot, and sonar control fully informed. CIC recommends courses and speeds for execution of search plans; is prepared to furnish firing times for throwing weapons and depth charges, if required; and also furnishes sonar control with information necessary for gaining or regaining contact. The geographic plot is the principal display equipment used in ASW. Surface plot and the PPI-scope also play an important part.

CIC also controls the attacking ship in certain types of multiship attacks, and may control own ship, if so directed.

7. *Air control.* In air control operations, CIC performs all five of its basic functions: collection, display, evaluation, dissemination, and control. Combat controls communications with airborne aircraft, controls aircraft on routine patrol stations, and controls interception of air contacts, when directed. Combat maintains the complete air picture on the air summary plot, follows individual raids and interceptions on the intercept plot, and performs all CAP control directly on the PPI-scope.

16F4. Conclusion

The combat information center is, briefly, an agency for the collection, display, evaluation, and dissemination of tactical information, and for facilitating the use of that information. CIC is not something strange and complex, nor is it merely a radar plot or an antisubmarine plot under another name. It provides a marked clarification and simplification of work for command. The captain receives information as he needs it; and he is free to concentrate on his decisions and carry the burden of command. He also has, in CIC, an organization to which he can delegate secondary decisions and control duties as the occasion may require.

Chapter 17

EXTERIOR BALLISTICS

A. Forces Affecting Trajectories

17A1. Introduction

Exterior ballistics is by definition that part of the study of ballistics which deals with projectile motion after the projectile leaves the gun. A study of the entire subject of exterior ballistics includes theoretical aspects of this motion, the forces affecting it, and also the practical problems of laying a gun so that a projectile fired from it will hit the target. This text will deal primarily with the practical aspects of exterior ballistics. In a study of the subject, however, it is desirable to examine the characteristics of trajectories in general, as well as characteristics of trajectories of projectiles fired under specific firing conditions.

17A2. Definitions

The first step in the study of exterior ballistics is an understanding of the characteristics of a trajectory and of the applicable definitions and symbols.

Symbol	*Definition*
	Horizontal plane. The imaginary plane tangent to the earth's surface at a point instantaneously occupied by own ship. Any plane parallel to this one is also horizontal. Angles or distance measured in a horizontal plane are called horizontal angles or distances and are usually identified by the letter *h*.
	Vertical plane. A plane perpendicular to the horizontal. Angles and distances measured in a vertical plane are called vertical angles or distances and are usually identified by the letter *v*.
	Trajectory. The path described by a projectile in flight.
R	*Range.* The distance from the origin of the trajectory to the target along the LOS.
Rh	*Horizontal Range.* The projection of the range in a horizontal plane.
LOS	*Line of sight.* The straight line joining the sight and the target.
E	*Position angle* or *target elevation.* The vertical angle between the LOS and the horizontal plane.
Eg	*Gun elevation* (*angle of elevation*). The vertical angle between the horizontal plane and the axis of the bore.
Vs	*Sight angle.* The vertical component of the angle between the line of sight and the axis of the bore.
	Angle of fall. The vertical angle between the horizontal and the tangent to the trajectory at the point of fall.
	Maximum ordinate. The vertical distance from the horizontal plane to the highest point of the trajectory.
Tf	*Time of flight.* The total time which elapses during the flight of the projectile from the gun to the point of fall (or burst).
Df	*Drift.* The lateral deviation of the trajectory from the vertical plane through the axis of the bore caused by the rotation of the projectile.
Ds	*Sight deflection.* The lateral component of the angle between the LOS and the axis of the bore.
I. V.	*Initial velocity* of the projectile with respect to the gun muzzle at the instant the projectile leaves the gun (normally given in foot-seconds [feet per second]).

17A3. Trajectory analysis

Theoretically, the curved path taken by a projectile fired from a gun, when projected in a *vertical plane,* is caused by the force of gravity acting on the projectile after it leaves the gun. The path, projected on a *horizontal* plane, is also a curve, due to gyroscopic properties imparted to the projectile by rotation caused by the rifling in the gun. The effect of this gyroscopic force is called drift, and it is always to the right, because naval guns are rifled with right-hand twist. There are, however, other factors in addition to gravity and gyroscopic precessional force which modify the curvature of a trajectory.

If the projectile traveled in a vacuum, the only external force acting upon it would be that of gravity. Under such circumstances, the result would be vertical deceleration in the ascending branch until the summit was reached, followed by an exactly equal acceleration in the descending branch to the point of fall. This would result in:

1. A trajectory in the form of a parabola with a vertical axis.
2. A maximum ordinate located halfway between the gun and the point of fall.
3. An angle of fall equal to the angle of elevation.
4. A striking velocity equal to the initial velocity.
5. A maximum range obtained from an angle of elevation of 45 degrees.

When the projectile is fired in air, the theoretical trajectory in a vacuum is modified by air resistance, with the following results:

1. The trajectory is not a true parabola.
2. The angle of fall is greater than the angle of elevation.
3. The striking velocity is less than the initial velocity.
4. The maximum range of the projectile is obtained not precisely at, but still close to, an angle of elevation of 45 degrees. For example, the maximum range of the 55.18-pound AA common projectile for the 5"/38 caliber gun is obtained with an angle of elevation of 44 degrees 35 minutes.

The following factors must be taken into account in ascertaining the difference in the trajectory characteristics of a projectile fired in air from the characteristics of one fired in a vacuum.

1. *The density of the atmosphere.* The air offers resistance to the projectile which materially alters the characteristics of the trajectory. Since atmospheric density differs from hour to hour with changes in temperature and barometric pressure, and also according to altitude, the resistance varies not only from time to time, but in the different altitude zones through which the projectile travels.

2. *Characteristics of the projectile.* The characteristics of a projectile which influence its retardation in passing through air of a given density are:
   a. Weight.
   b. Cross-sectional area, which is proportional to the square of the projectile's diameter.
   c. Shape. A projectile which has a streamlined front end encounters less resistance than one which has a short, blunt nose. The shape of the base also affects resistance.

3. *The initial velocity.* With air density and projectile design constant, initial velocity affects the characteristics of the trajectory, because the amount of resistance offered by air varies with velocity.

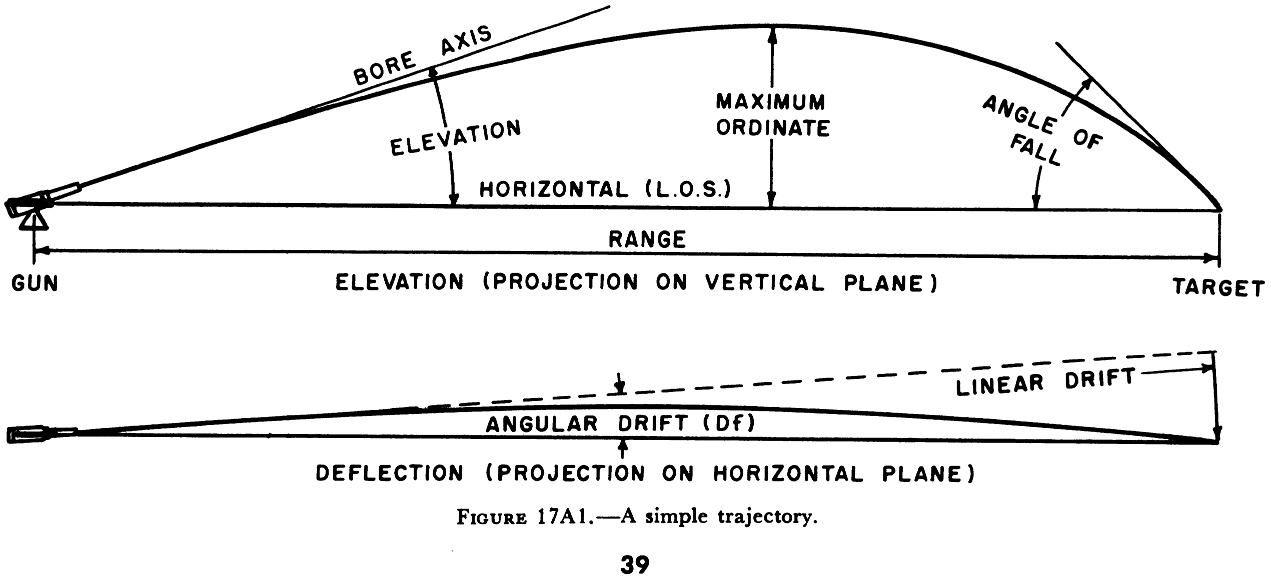

Figure 17A1.—A simple trajectory.

17A4. Elements of a trajectory

Since the trajectory is curved, because of the factors mentioned, it is obvious that the bore of the gun cannot be pointed directly at the target (except at point-blank ranges), but that it must be directed at some other position in space, as shown in figure 17A1. The projectile must describe a definite trajectory in order to hit the target. To obtain this trajectory, the gun must be laid accurately with respect to some reference plane or line. The horizontal plane provides a convenient reference plane from which the vertical angle may be measured. If the gun is mounted on a platform ashore it can be laid from the horizontal plane to the desired elevation by the use of a gunner's quadrant, an instrument which measures angles of elevation with respect to the true horizontal. At sea such a method is impracticable because of ship's motion. The most convenient reference is a line joining the positions of gun and target. Since it is normally the line along which the target is sighted from the gun, it is called the *line of sight*. Laying the gun with respect to this reference line is shown in figure 17A2. It is apparent from the figure that the gun elevation *Eg* remains constant as the ship rolls, as long as the LOS is held on the target.

The vertical angle through which the gun is elevated with respect to the *horizontal* is defined as the *angle of elevation*. If the trunnion axis is horizontal, the vertical angle between the axis of the bore and the line of sight is the same as the sight angle (*Vs*).

The lateral angular offset of the bore axis from the LOS due to the drift of the projectile is called drift (*Df*). The *total* lateral angle due to all factors causing deflection is called sight deflection (*Ds*).

17A5. Drift

The drift of an elongated, rotating projectile may be considered to result from three causes:

1. Gyroscopic action.
2. The Magnus effect.
3. The cushioning effect.

It is reasonably certain that the last two causes have only a minor effect as compared with the first.

The rifling of the gun barrel causes the projectile to rotate in flight with sufficient rapidity to behave as a gyroscope. This serves to stabilize the flight of the projectile, but it makes the projectile subject to gyroscopic precession. Because of the curvature of the trajectory, air pressure on the underside of the nose of the projectile causes a precession to the right. This shift of the projectile axis to the right increases the air pressure on the left-hand side of the nose, which causes the projectile to precess downward. This train of events continues, causing the axis of the projectile to oscillate about the tangent to the trajectory. Since the greatest pressure is on the underside of the nose, the over-all precession is to the right.

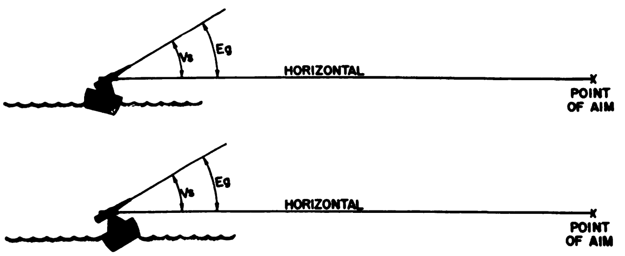

Figure 17A2.—Positioning a gun on a moving ship.

The initial tendency of a projectile to maintain the original direction of its axis as it falls away from the axis of the bore causes the air stream to strike the projectile's lower side. With right-hand spin, the air adhering to the right-hand side of the projectile then opposes the air stream created by the projectile's flight, and the result is an increase of pressure on the right-hand side. At the same time, there is a rarefaction, and the projectile tends to move to the left, to the side of lesser pressure. This effect is known as the Magnus effect, and is the same phenomenon which causes a golf ball to hook or slice. The Magnus effect can be important on the descending end of the trajectory at extreme elevations.

Since the air tends to pile up on the underside of a projectile in motion, it forms a cushion. The projectile tends to roll on this cushion because of the friction imposed by it. This movement is to the right in a projectile with right-hand spin, opposing the Magnus effect but adding to the gyroscopic effect.

17A6. The principle of rigidity of the trajectory

When a gun is elevated with respect to its LOS, it is not necessarily elevated with respect to the horizontal, because the gun and target may not lie in the same horizontal plane. Assuming that the water's surface is the horizontal, the gun is placed somewhat above this surface, the exact distance depending on its location aboard ship. The LOS is normally directed at the waterline when the target is a ship. In this case, the LOS dips below the horizontal by the amount of the position angle *E*.

In the surface fire this angle *E* is small and may be neglected because of the *principle of rigidity of the trajectoty*. This principle states that *for small angles of position*, a gun which obtains a certain inclined range along a line of position, when elevated the required angle above that line, will have the same range along the horizontal when elevated the same angle above the horizontal.

In surface fire it is unusual to encounter a position

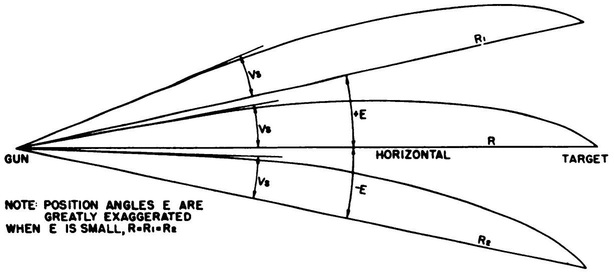

FIGURE 17A3.—Rigidity of the trajectory for small position angles.

angle of more than about 35 minutes, and a value as great as this occurs only at extremely short range, in which case the gun elevation angle is also small. For example, with a 5"/38 caliber gun mounted 50 feet above the waterline and firing at the waterline of a target at a slant range along the LOS of 1,600 yards, the position angle is about −35 minutes and the gun elevation angle is +43.6 minutes. For these values of *E* and *Eg,* the ratio of the inclined range *R* to the horizontal range *Eh* is about 1.0001, showing that the difference in range is negligible. Therefore, even though the angles of elevation listed in the range tables are values of *Eg* (vertical angles measured with respect to the horizontal), these angles, when set on the gun sights as *Vs* (measured with respect to the line of position), result in the required ranges along the LOS, with insignificant error. This principle is applied only in surface fire, where the angles of position are normally small.

The principle of trajectory rigidity does not hold in AA fire, because normally the position angle is considerably larger.

B. Range Tables

17B1. Preparation of range tables

For service use, the Bureau of Ordnance publishes for each gun and for each projectile type fired by the gun, a *range table,* which presents, in convenient form for reference, the elements of the trajectories resulting from firing that specified projectile, at a specified initial velocity at various angles of elevation under standard conditions (which will be described later). A range table tabulates, for each 100-yard increment of range, such characteristics of the trajectory as angle of elevation, time of flight, angle of fall, and striking velocity.

It would obviously be impracticable to measure directly all the elements of the various trajectories, data for which appear in a range table. Neither is there a single simple equation whose solution will give the characteristics of a trajectory at any point, principally because of complications introduced by air resistance. The actual preparation of the range table involves experimental firings of a small number of the specified projectiles to obtain data which are used in conjunction with a complex set of equations or formulas to solve the trajectory.

The equations require (in addition to values of initial velocity and angle of departure) a value known as the Ballistic Coefficient, *C,* for their solution. This coefficient is a measure of comparison between the retardation of the specific projectile for which the range table is being prepared and the retardation of a projectile of a specific standard form in air of an arbitrarily chosen standard density. The expression for *C* is:

$C=\frac{w}{id^2}$, where

w = weight of projectile in pounds.
d = diameter of the projectile in inches.
i = coefficient of form (the ratio of the retardation of the given projectile to that of a projectile of standard characteristics).

The retardation of the projectile of standard characteristics which is being used as a basis for comparison is available in either the form of a drag coefficient or the form of a resistance curve. The data for such a drag coefficient or resistance curve are available from measurements obtained by actual experimental firings of the standard projectile. It should be noted that *i* will include not only retardation relations based on form, but any factors, other than weight and diameter, which affect retardation.

The value of the coefficient of form, *i,* is determined by experimental ranging at the Naval Proving Ground. A number of shots (from four to seven) are fired at each angle of elevation in a series such as the following: 5°, 15°, 20°, 30°, 45°, and again at 15 degrees. The velocity is measured at each angle. Throughout the firing, meteorological observations are made, at the surface and aloft, to determine wind, temperature, and atmospheric density. On the basis of these observations computations are made for ballistic density and ballistic wind for the predicted height of maximum ordinate. Since the projectile travels through various altitude zones, it is clear that values of wind, temperature, and density do not remain the same throughout the trajectory. Therefore, fictitious values of wind and air density are computed which represent a constant value for each over the entire trajectory. The fictitious values are called ballistic density, ballistic wind, and ballistic temperature; they are used for correcting the trajectories derived from observed data to those which would exist in the arbitrarily defined standard atmosphere on which retardation of the standard projectile is based.

Uncorrected observed ranges are recorded and averaged for each angle of elevation. These ranges are then corrected for errors due to: (1) the height of the gun above tide level, (2) the curvature of the earth, (3) jump, and (4) rotation of the earth. These corrections are in addition to the corrections for ballistic temperature, wind, and density mentioned above. The first two corrections mentioned in this paragraph permit the range table to conform to the requirement that the point of fall be in the horizontal plane tangent to the earth at the gun.

The corrected observed values are used to obtain a final coefficient of form, *i*, for each of the angles of elevation. From this the value of *C* for the designed weight and diameter of the projectile can be computed.

The observed lateral deviation is corrected for the effect of the componet of wind acting at right angles to the line of fire and for rotation of the earth. The remaining deviation is the *observed drift*.

The formulas mentioned above can be used to solve for the elements at points on the trajectory, since the value of *C* is now available. Formerly, these formulas were worked out and assembled in *ballistic tables* for a number of combinations of the variables involved. The entering arguments of such a table are *Eg,* I. V. and *C*. From any combination of these three values it was possible to pick off the required values for the range table such as Range, Time of Flight, Angle of Fall, Maximum Ordinate, *etc*. The *ballistic table* can thus be considered as a master range table. It should be obvious that compilation of ballistic tables and construction of range tables from them entail much complicated and tedious work.

Current practice at the Naval Proving Ground is to compute all range table entries directly from the equations by means of large mechanical and electronic computing machines. These machines are capable of handling a large number of complex solutions rapidly and accurately, thus eliminating the need for ballistic tables. Obviously, in using computing machines in the preparation of range tables instead of using ballistic tables, a different method of arriving at the desired value is used rather than a change in basic principle of solution of the trajectory.

The computation of drift for standard conditions is a separate calculation involving the use of the observed drift in a special formula.

17B2. Standard conditions for range tables

In the computations upon which range tables are based, certain arbitrary conditions are assumed. These arbitrary conditions are generally spoken of as *range-table standard conditions*. In order to use the range table under conditions other than standard, it is necessary to provide in the range table, corrections for variations from these conditions.

The standard conditions assumed for range-table values are that:

1. The projectile leaves the gun with the designed velocity.
2. The projectile is of the designed weight.
3. The atmosphere is of an arbitrarily chosen standard density.
4. There is no wind.
5. The gun is motionless.
6. The target is motionless.*
7. The earth is motionless.
8. The gun and target are in the same horizontal plane, the plane tangent to the earth's surface at the gun.
9. The gun is elevated in the vertical plane; that is, the axis of the gun trunnions is horizontal at the time of firing.

Since the range table is based upon these conditions, variations from any one of them may cause a significant error. In addition to the tabulation of trajectories under standard conditions, the range table provides necessary corrections for variations from the first six of these standard conditions. Corrections for variations from any of the last three require separate consideration or computation.

Correction for rotation of the earth can be computed from auxiliary tables published with range tables for major-caliber guns, or by fire control instruments. The amount and direction of the error vary with the azimuth of the LOF, the latitude, and the range; but remain small in all cases. The correction is disregarded for guns of 5-inch caliber or smaller. The effect of firing at a target not in the horizontal plane of fire was discussed in article 17A6. The correction for tilt of the trunnion axis from the horizontal is practical only when using a mechanical solution and therefore is considered in chapter 19. Use of the columns of the range table to account for nonstandard conditions will be taken up in the next section of this chapter.

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*Although motion of the target does not affect the trajectory itself, it enters into the problem of determining the trajectory that will reach the target.

17B3. A typical range table

Appendix B contains extracts from the range table for the 8"/55 gun. The discussion which follows in this chapter, however, is based on the range table for the 5"/38 gun, which appears in appendix C. The discussion in section C of this chapter, "Practical Application of Range Tables," is also based on the 5"/38 gun; and the tabular summaries of computations employ figures for the 5"/38 gun. A similar group of tabular summaries employing figures for the 8"/55 gun appears as part 6 of appendix B. The student may refer to these summaries also during the following discussion, since the computations are for the most part identical with those for the 5"/38 gun.

The range table shown in appendix C is for a 5"/38 caliber gun using a 55.18-pound AA common projectile. The table is based on an initial velocity of 2,500 foot-seconds, which is the average velocity obtained throughout the service life of a gun, instead of the value of 2,600 foot-seconds, which is the designed new-gun standard initial velocity. The use of such a base makes the required amount of correction from standard conditions smaller, considering the life of the gun, and therefore promotes accuracy in the final results.

Columns 1 to 8, inclusive, of the range table give values of elements of the trajectory, under standard conditions, corresponding to a given range, in increments of 100 yards. Columns 10 through 18 (there is no column 9) are needed because actual firing is seldom, if ever, conducted under standard range-table conditions. To compute accurate values for *Vs*, (sight angle) and *Ds* (sight deflection) under actual firing conditions, it is necessary to determine corrections to the trajectory for any variations from standard.

The errors tabulated in columns 10 through 18 of the range table are those caused by a variation of +10 foot-seconds in initial velocity, −1 pound of projectile weight, −10 percent atmospheric density, −10° F. in temperature, or 10-knot components of wind, target, or gun motion. The sign is merely for convenience, so the tabulated values will usually be positive and not require a sign. Whether the correction is positive or negative will be readily apparent under the particular set of conditions of the problem.

17B4. Column 10

Column 10 is headed "Change of range for variation of +10 feet per second initial velocity." The sole use of the plus sign in the heading is to indicate the direction of the error in range resulting from a variation from standard initial velocity, an increase in initial velocity naturally causing an increase in range.

The two elements which affect initial velocity are gun erosion and variation in powder temperature. Of these, erosion causes a loss in initial velocity and a decrease in range. The Navy range tables are based on a *standard* powder temperature of 90° Fahrenheit. Since magazine ventilation is regulated to ensure that the temperature in magazines hardly ever exceeds this figure, it is obvious that an increase in initial velocity due to powder temperature seldom occurs. (It may occur if ammunition from ready lockers, located topside, is used.) The variation in velocity due to temperature variation of one degree from 90° F. is stated in certain range tables and other Bureau of Ordnance publications, a reduction in powder temperature causing a loss in velocity. The loss of initial velocity per degree change of powder temperature will vary with the caliber and powder index. However, 2 foot-seconds per degree F. change of powder temperature is about average, and will be used in this text for simplicity.

The loss of velocity caused by erosion is dependent upon the amount of bore enlargement, as was discussed in chapter 5 of this text. The range table includes one graph which shows the amount of velocity loss for specified amounts of bore enlargement, which can be used following star gaging, and a second graph showing bore enlargement versus equivalent service rounds fired, for use in periods between star gaging.

It must be noted that the loss of initial velocity for bore enlargement is, in the case of the 5"/38 caliber gun, a loss from new-gun standard I. V. of 2,500 foot-seconds, the average velocity during the life of the gun; therefore, in a relatively new gun, velocity change due to bore enlargement may have to be computed, in relation to the range table, as a gain.

Having obtained the velocity loss from powder temperature and erosion data, as described above, one may determine the resulting range error from column 10.

Example: Find the range error due to a loss of initial velocity of 126 foot-seconds from new-gun standard for the 5"/38 caliber gun, firing at a range 10,000 yards.

Solution: From column 10, at range 10,000 yards, the error in range for a loss of velocity equal to 10 foot-seconds is −48 yards. A loss of 126 foot-seconds from 2,600 foot-seconds represents a loss of 26 foot-seconds from the range-table initial velocity. The error due to a loss of 26 foot-seconds is $^{26}/_{10} \times (-)48 = -125$ yards, or 125 yards *short.*

Note: A shot falling short of the target is termed a *short,* while one falling beyond the target is an *over.* *Shorts* and *overs* are corrected by *add* and *drop* spots, respectively.

17B5. Column 11

Column 11 is headed "Change of range for variation of −1 pound in weight of projectile." This change of range is due to two causes which are opposite in their effects. The first is the change in the initial velocity. A projectile heavier than standard will be expelled from the gun at lower than designed muzzle velocity, causing a decrease in range. However, increase in weight will cause an increase in value of the ballistic coefficient and, since retardation varies inversely as the value of the ballistic coefficient, this causes an increase in range.

Referring to the range table in appendix C, part 2, it is seen that at short ranges, the effect on initial velocity is the predominant factor, while at long ranges, the effect on ballistic coefficient has the greater significance. At a range of 6,700 yards (in this table) the effects exactly cancel each other and the net error is zero.

In practice, column 11 is not normally used aboard ship. It would be used if projectiles of other than standard weight were to be fired. Projectiles are required to be of designed weight within small tolerances, and the effects of these small variations are neglected, since it would obviously be impracticable to weigh each projectile or to make a correction for each gun before firing each salvo. It is apparent, however, that this variation in projectile weight is one reason why all shots of a salvo, fired at the same time and under the same conditions, do not fall at the same point.

17B6. Column 12

Column 12 is headed "Change of range for variation in density of air of −10 percent." For use under conditions where no aloft observations of air density are possible, a table has been prepared based on the results of many past observations aloft. The entering arguments are the height of the maximum ordinate in feet and the surface density; the result is the ballistic density. Standard surface density has been arbitrarily selected as the density of the atmosphere which results from a temperature of 59° F., a barometric pressure of 29.53 inches of mercury, and a humidity of 78 percent saturation. This standard surface density is assigned a numerical value of 1,000. To determine the variation in the trajectory caused by variation from standard surface density, the temperature and barometric pressure are measured at the surface and the resulting density is expressed as a percentage of the standard. (Variations from standard percentage of saturation are neglected.) This percentage of standard density at the surface is then used as an entering argument to the table of ballistic density (not shown in the appendix) and from it the ballistic density is found.

The minus sign in the heading of column 12 indicates that a reduction in air density causes an increase in range, the plus sign in the column being understood. Conversely, an increase in air density causes a decrease in range. In order to use the table for a given ballistic density, it is necessary to compare the percentage variations from standard with the 10-percent variation from standard on which the column is based.

Example: Given ballistic density of 1.059, find from column 12 the range error resulting from the nonstandard atmosphere, for the 5″/38 caliber, 2,500-foot-second gun, firing at a range of 10,000 yards.

Solution: The percentage variation from standard is $1.059 - 1.000 = (+)\ 0.059 = (+)\ 5.9$ percent. The value in column 12 is based on a (−) 10-percent variation from standard. The value taken from the column must, therefore, have a minus sign and the error is $\frac{5.9}{10} \times (-)501 = -296$ yards, or 296 yards *short.*

Note that the *correction* to compensate for this error in range is ADD 296 YARDS.

17B7. Use of the nomogram

An alternate means of determining the change of range for variation of air density is by *nomogram.* The nomogram provided with the 5″/38 caliber range table (appendix C, pt. 1) is an example of the type in use in the fleet today. When aloft aerological observations are not available, it gives a rapid solution of the error in range due to variation in atmospheric density. Instructions for its use are provided with the nomogram.

Example: Find the error in range for the 5″/38 caliber 2,500-foot-second gun, firing at range 10,000 yards, due to surface air temperature of 40° F. and surface barometric pressure of 30.10 inches of mercury.

Solution: Alignment of 40° and 30″.10 provides a point on the support line of the nomogram, which is the equivalent of determining the surface density. Alignment of that point with 10,000 on scale R gives an error in range of −280 yards. The necessary correction is, therefore, ADD 280 YARDS.

The use of the nomogram is more accurate than results obtained from using column 12 with surface observations, as it takes into account the ratio between mean measured and standard density for the actual maximum ordinate obtained.

NOTE: Some recent range tables, including the one reproduced in appendix C, have an additional column, 12a, which gives the change of range for a variation of temperature of the air of 10° F. from the standard air temperature. The effect given in column 12a is that caused by change in the elasticity of the air and is independent of and additional to the effect of any change in density. Column 12a is used with surface air temperature; the standard being taken as 59° F.

17B8. Columns 15 and 18

Column 15 is headed "Change of range for motion of target in plane of fire of 10 knots," and column 18 is headed "Deviation for lateral motion of target perpendicular to line of fire, speed of 10 knots." Actually, column 15 gives the distance that the target will move in the line of fire, if its speed *in the line of fire* is 10 knots, during the time of flight of the projectile. Column 18 gives the same information for motion across the line of fire. The values in the columns are derived by multiplying the speed of 10 knots, expressed as 16.89/3 yards per second, by the time of flight of the projectile for the given range, as found in column 4 of the range table.

Example: Find the errors in range and deflection caused by motion of a target, the components of whose speed are 16 knots in the line of fire and 13 knots across the line of fire, the firing ship being on the starboard bow of the target, range 10,000 yards.

Solution: Since the values in both columns 15 and 18 are found by multiplying speed components of 10 knots by time of flight, these values are identical, and are in this case 124 yards.

Then, in range, $^{16}/_{10} \times 124 = 198$ yards that the target will move toward the firing ship during the time of flight. The *correction* to compensate for this motion must be DROP 198 YARDS.

Across the line of fire the target will move $^{13}/_{10} \times 124 = 161$ yards to the right, and the *correction* to compensate for this motion must be to the right also.

It should be noted that target motion toward the firing ship will cause an error which is *over* in direction; also that target motion to the right will cause the projectile to fall to *left* of the target position at the end of the time of flight. The *correction,* in each case, is in the direction of motion of the target.

17B9. Columns 13 and 16

Column 13 is headed "Change of range for wind component in plane of fire of 10 knots," and column 16 is headed "Deviation for lateral wind component of 10 knots."

A wind, or wind component, in the plane of fire, or line of fire, is spoken of as a *range wind.* A lateral wind (wind, or wind component, blowing across the line of fire) is spoken of as a *cross wind.*

The effect of a positive range wind (blowing in the direction in which the projectile is traveling) is to increase the range. The opposite is true for a negative range wind. A cross wind will carry the projectile in the direction toward which the wind is blowing. The method of deriving the values in these columns is quite involved, and will not be treated in this text.

The use of the columns is similar to that described in article 17B8, and will not be repeated. The direction of the errors having been found, care must be taken to apply the corrections in the proper direction. The *error* is in the direction toward which the wind is blowing; hence the *correction* must be in the *opposite* direction.

17B10. Columns 14 and 17

Column 14 is headed "change of range for motion of gun in plane of fire of 10 knots," and column 17 is headed "Deviation for lateral motion of gun perpendicular to line of fire, speed, of 10 knots." By "motion of gun" is meant the *velocity imparted to the projectile due to motion of the firing ship,* aside from the velocity imparted by the powder charge. This velocity may be positive or negative. Thus, a ship steaming at 10 knots and firing dead ahead imparts an added velocity of 16.89 foot-seconds, *in the horizontal plane.* The same ship firing dead astern reduces the horizontal component of initial velocity by the same amount. Firing on the beam causes a velocity component across the line of fire in the direction of motion of the ship.

If the gun were fired—and the projectile were to travel—in a vacuum, the range error could easily be determined. In the case of firing dead ahead, the range would be increased by $16.89 \times Tf/3$ yards. But this is the value found in columns 15 and 18, since the target motion was computed by using this very formula and with these same values.

However, the gun is not fired in a vacuum but in the resisting medium of the atmosphere. If no wind is blowing, a person standing on deck on a moving vessel will feel an apparent wind, equal in force to the speed of the vessel. It may therefore be said that a projectile fired from a moving vessel, *in still air,* is opposed by an apparent wind equal in force but opposite in direction to the motion of the vessel. The effect of such an opposing wind may be found in column 13 for range wind and in column 16 for cross wind.

The above discussion leads to the statement that "the effect of a given component of gun motion is, *numerically,* the *equivalent* of the effect of an equal component of target motion less the effect of an equal component of wind." This does not mean that target motion, as such, enters into the problem in any way. It does mean that the value of the change of range if the gun were fired in a vacuum, would be computed in the same manner in which the effect of target motion is computed. This value is found in columns 15 and 18, which are tabulated as *target motion.* However, since the gun is fired in air, this effect is *opposed* by a force which is the same as that of an equal component of wind blowing against the projectile. This relation should be thoroughly understood, as it will be employed repeatedly in this text.

This statement may also be expressed as:

Column 14 = column 15 − column 13, and
Column 17 = column 18 − column 16.

Examination of any range table for any range shows that this relation is true. (The occasional difference of 2 or 3 yards is due to the fact that columns 14 and 17 actually are computed from formulas, the results plotted, and the curves faired.)

17B11. Danger space and hitting space

For a given target and trajectory, the *danger space* is the greatest distance through which the target may be moved in the line of fire and still be intersected at some point by that trajectory. Column 7 of the range table is composed of values of the danger space for a target 20 feet high and of zero depth in the line of fire.

Referring to the 5″/38 range table, range 10,000 yards, it is seen that the danger space is 18 yards. The value of the danger space at this range for a target 30 feet high is $30/20 \times 18 = 27$ yards. Now if this 30-foot target has a beam of 105 feet (35 yards) it is apparent that its danger space is $27 + 35 = 62$ yards.

Hitting space is defined as the variation in sight-bar range, at a fixed target distance, between the trajectory which intersects a given target at the waterline and the trajectory which intersects the top of the target. Column 19 of the range table, headed "Change in height of impact for variation of 100 yards in sight bar," is the column used for determining hitting space. (Sight-bar range is the range shown on the sight scale of the gun at the instant of firing.)

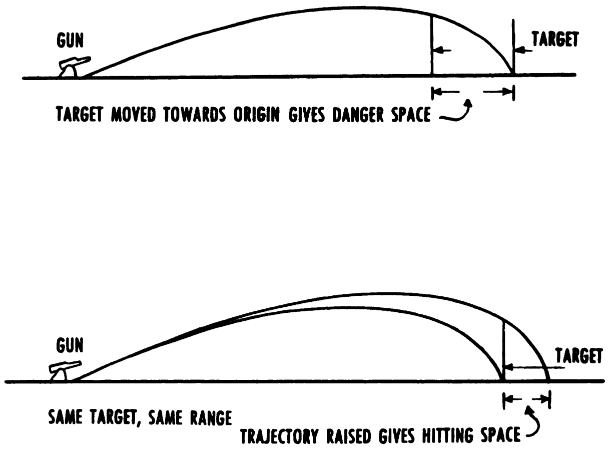
GUN
TARGET
TARGET MOVED TOWARDS ORIGIN GIVES DANGER SPACE
GUN
TARGET
SAME TARGET, SAME RANGE
TRAJECTORY RAISED GIVES HITTING SPACE

FIGURE 17B1.—Danger space and hitting space.

To find the hitting space for a 20-foot target at range 10,000 yards, column 19 is entered, and the value obtained is 112 feet; *i. e.,* a variation in sight-bar range of 100 yards will move the point of impact 112 feet in the vertical plane of the target. To raise the point of impact 20 feet (to the top of the target) the sight-bar range would have to be increased $\frac{20}{112} \times 100 = 18$ yards.

This value for hitting space is the same as that earlier obtained for danger space. For most battle ranges this relationship holds; for the shorter ranges, however, there may be a considerable difference. For example with a 20-foot target at 3,500 yards the range table gives a danger space (column 7) of 157 yards and a hitting space of $\frac{20}{14}$ (column 19) $\times 100 = 143$ yards.

Figure 17B1 illustrates danger space and hitting space and emphasizes the difference between the two terms.

C. Practical Application of Range Tables

17C1. Definitions

For shipboard firings, it is necessary to determine, or to estimate, the variations from range-table standard conditions as they exist at the time of firing, and to compute corrections for the errors caused by these variations. The individual corrections are summarized and the result is called a *ballistic correction.*

Before this process can be described, it is necessary that the following terms be understood:

Line of sight (LOS) is the straight line joining the sight and the point of aim. The *line of fire* (LOF) is the line joining the gun and the point of impact (or burst) of the projectile. The headings of some range-table columns speak of the "plane of fire," others of the "line of fire." The plane of fire is the vertical plane through the line of fire. In this section no distinction will be made between "line of fire" and "line of sight." It will be noted that the difference between the LOF and the LOS, if the problem is solved correctly, is that the LOS is based on present target position at the time of firing, while the LOF is based on the predicted target position. The errors caused by constructing the angles for target, wind, and own-ship motion about the LOS instead of the LOF are negligible in the case of surface-target firing. Only in antiaircraft fire, where the target speed is very high and the sight deflection or *lead angle* may be very large, is it necessary to differentiate between LOS and LOF.

Relative target bearing (*Br*) is the direction of the target from the firing ship, relative to the bow of the firing ship. It is measured in a horizontal plane, clockwise from the bow of the firing ship to the line of sight, from zero to 360 degrees.

True target bearing (*B*) is the direction of the target from the firing ship, relative to geographic north. It is measured clockwise in a horizontal plane from true north to the line of sight, from zero to 360 degrees.

Target angle (*A*) is the relative bearing of the firing ship from the target. It is measured in a horizontal plane clockwise from the target's bow to the firing ship, from zero to 360 degrees. (It must be understood that the line of sight, as defined above, is directional. To express the direction from target to firing ship, the expression "line of sight, reversed" is used. Thus, target angle is often defined as "the bearing of the firing ship from the target, measured from the target's bow clockwise to the line of sight, reversed.")

True wind is the wind as it exists with respect to the earth and independent of any motion of the ship.

Apparent wind is the wind which is apparent to an observing station which is itself in motion. It is the vectorial resultant of the motion of the true wind and the reversed motion of the observing station.

Ballistic wind is a value of wind speed and direction which is considered to be the resultant of the effect of all the true winds acting upon the projectile in flight. Winds at various altitudes generally differ in force and direction from wind at the surface. Consequently, to calculate the effect of wind throughout the trajectory, it is necessary to measure, at regular increments of altitude, the actual force and direction of the wind, and to weight the effect according to the length of time the projectile will travel through each stratum of wind. The resultant, computed as a vectorial sum, is used as though it were a uniform wind, constant throughout the trajectory. This method of determining ballistic wind is used at the Naval Proving Ground when ranging shots are being fired. Its use under service conditions is ordinarily impracticable except when an aerological unit is present, although an approximation may be obtained by following a balloon with an AA director. If no means is available for determining ballistic wind, corrections for wind are based on the existing surface wind.

Wind direction is the direction from which the wind is blowing. The term is applied to either true or apparent wind.

17C2. The line-of-sight diagram

In order to compute the errors caused by target motion, wind motion, and firing-ship (gun) motion, it is necessary to resolve these motions vectorially into components, in and across the line of sight. The diagram which is employed is called a vector diagram. A simple problem, with explanation of each step, will best illustrate how this solution is obtained.

Given:

5"/38 caliber gun.
Range, 10,000 yards.
Relative target bearing, 300 degrees.
Target angle, 80 degrees.
Wind direction, true wind, 255° relative.
Firing ship's speed, 18 knots.
Wind velocity, 10 knots.
Target speed, 20 knots.

Required:

Draw the vector diagram for this situation; compute the components of gun, wind, and target motions in and across the line of sight. Determine whether the resulting *errors* will be over or short in range and right or left in deflection.

Solution:

a. Draw a vertical line representing the *direction* of the line of sight. *This is* always *drawn as a vertical line with own ship* (*gun*) *at the bottom of the line.* Mark the points, T, W, and G from which to draw vectors for target, wind, and gun motions, respectively.

b. Since relative target bearing is 300°, the angle measured clockwise from firing ship's bow to the LOS is 300 degrees. The gun-motion vector is drawn making this angle with the LOS. The acute angle between the gun's vector and the LOS is seen to be 60 degrees. (The acute angle is used in the determination of the components.) By trigonometry, the component of gun motion in the LOS is 18 cos 60°, or 9.0 knots, and the component across the LOS is 18 sin 60°, or 15.6 knots, as shown in figure 17C1.

The component in the LOS, in this case, results in imparting to the projectile an added velocity which causes increase in the range over that which would be attained were the firing ship stationary. Had the gun component in the LOS been in the opposite direction, or away from the target, the result would have been a decrease in the range. It must be stressed that motion of the firing ship after the projectile has left the gun can in no way affect the trajectory. What is of concern is the velocity (positive or negative) imparted to the projectile by the motion of the firing ship. In this case the range is increased, and the error is *over*. The vector should be so labeled.

By the same reasoning, the gun motion component across the LOS imparts a lateral velocity and a deflection error in the direction of the component. In this case the error is *right* and the vector should be so labeled.

c. From W lay off the true-wind vector for a wind direction relative to the bow of the firing ship equal to 255 degrees. (Since no compass courses or bearings were stated, the direction of the true wind could not be expressed as a true bearing.) The bearing of the LOS is 300° from the bow of the firing ship. Hence the direction *from which the wind is blowing*, with respect to the LOS, is 255° − 300° = (−) 45°. This angle is laid off at W, counterclockwise from the LOS. Since the wind is blowing from that direction through W, the wind vector is shown with its foot at W. Confusion in this vectorial representation very frequently arises because, by custom, we refer to the direction or bearing of the wind in the opposite sense to that indicated by the vector; *i. e.*, the expressed direction is that *from* which the wind is blowing, while the vector indicates, as in all cases of motion, the direction *toward* which the movement is taking place. It is helpful to practice with examples in each of the quadrants and with different relative target bearings.

Since the wind velocity is 10 knots, the component in the LOS is 10 cos 45°=7.1 knots. The result of this wind component, acting on the projectile during the time of flight, is to cause a reduction in the range, or a *short* error. The component across the LOS, 10 sin 45° = 7.1 knots, blows the projectile to the right, causing a *right* error in deflection. The vector should be labeled *short* and *right*.

d. From T lay off the target vector so that the target angle equals 80 degrees. The component in the LOS is 20 cos 80° = 3.5 knots, and across the LOS is 20 sin 80° = 19.7 knots.

During the time of flight the target is decreasing the range at the rate of 3.5 knots, and a projectile fired with the given range setting will fall beyond the target's position at the end of the time of flight. Hence the range error caused by this motion of the target is *over*. Also since the target moves to the right the projectile will fall to the *left* of the position of the target at the end of the time of flight, or the error in deflection will be *left*. The vector is therefore labeled *over* and *left*.

e. Having determined the direction of the *errors*, in range and in deflection, caused by gun, wind, and target motions, it is now necessary to determine, from columns 13–18, inclusive, the amounts of these errors *in yards*. It is convenient, however, to summarize these errors with the range errors caused by variations in initial velocity and atmospheric density, and with the deflection error caused by drift.

17C3. The gun ballistic correction

In gunnery, a correction for an error in range or in deflection is known as a *ballistic correction*. The ballistic correction to compensate for the errors noted below is known as the *gun ballistic correction*. These elements are:

In Range

1. Variation in powder temperature.
2. Velocity loss due to gun erosion.
3. Variation in air density.
4. Target motion in the LOS.
5. Wind motion in the LOS.
6. Guns velocity in the LOS.

In Deflection

1. Drift.
2. Target motion across the LOS.
3. Wind across the LOS.
4. Gun's velocity across the LOS.

The example given in article 17C2 will be continued to find the gun ballistic for that situation, with further variations due to powder temperature 80° F., velocity loss due to erosion 18 foot-seconds (below 2,500 foot-seconds), and atmospheric density corresponding to surface air temperature 52° F. and barometer 30″.40.

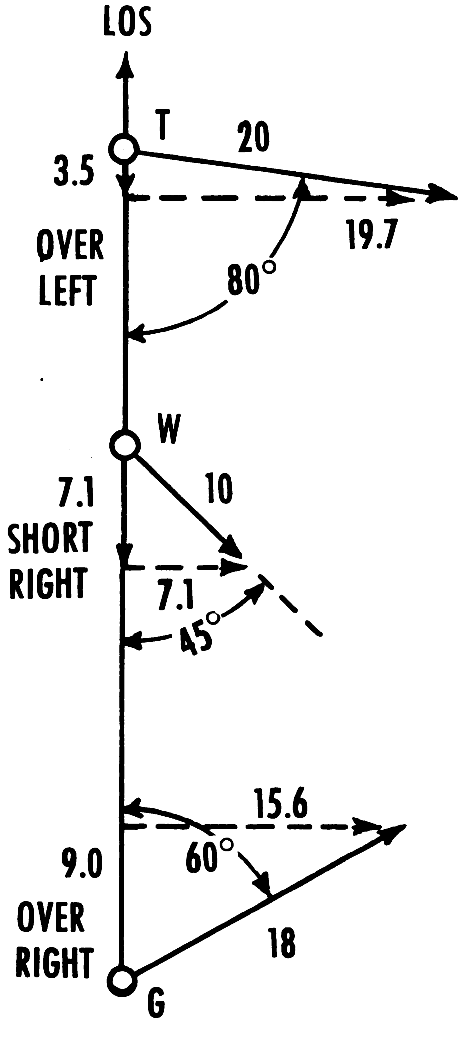

FIGURE 17C1.—Line of sight diagram (using true wind).

The multiplier for column 12 (variation in air density) is found by first obtaining from the aerological party a value of ballistic density factor, in this case 1.043.

$-1.043=-043=(-)4.3\%$

Since column 12 is based on a 10 percent variation, the multiplier is $(-)\frac{4.3}{10}$, or $(-)$ 0.43. The minus sign indicates that the range error will be *short*.

The powder temperature is 10° less than standard, causing a velocity loss of $2\times 10=20$ foot-seconds.

The six range elements will be summarized: (See also appendix B, part 6.)

The errors in range are:		*Over*	*Short*
1. Powder temp.	Col. 10: $\frac{20}{10}\times 48=$	*X*	96
2. Erosion loss	Col. 10: $\frac{18}{10}\times 48=$	*X*	86
3. Air density	Col. 12: $(-)0.43\times 501=$	*X*	215
4. Target in LOS	Col. 15: $\frac{3.5}{10}\times 124=$	43	*X*
5. Wind in LOS	Col. 13: $\frac{7.1}{10}\times 78=$	*X*	55
6. Gun in LOS	Col. 14: $\frac{9.0}{10}\times 46=$	41	*X*
7. Sum		84	452
		Drop	Add
8. Computed gun ballistic correction in range (yards)		*X*	368

Note the arrangement of column headings. Item 7 shows the sums of the over and short *errors*. Item 8 shows the algebraic sum of these errors ($452-84=368$), tabulated in the same column as the larger of the two. However, between items 7 and 8 the column headings are changed, so that the computed *gun ballistic correction* may be read as it will be used. Obviously a summation of range errors which is 368 yards short will require a correction of Add 368 yards.

The errors in deflection will now be summarized and the gun ballistic in deflection obtained. Note the change in column headings between lines 5 and 6. (See also appendix B, part 6.)

The errors in deflection are:		*Right*	*Left*
1. Drift	Col. 6	69	*X*
2. Target across LOS	Col. 18: $\frac{19.7}{10}\times 124=$	*X*	244
3. Wind across LOS	Col. 16: $\frac{7.1}{10}\times 53=$	38	*X*
4. Gun across LOS	Col. 17: $\frac{15.6}{10}\times 71=$	111	*X*
5. Sum		218	244
		Left	Right
6. Computed gun ballistic correction in deflection (yards)		*X*	26

The algebraic sum of the *errors* is 26 yards to the left. The shift in the column headings allows the computed gun ballistic correction to be read directly as right 26 yards. Caution must be exercised in reading the direction of the correction as shown directly above line 6, and not at the top of the column.

As a last step, it is necessary to convert the ballistic correction in deflection from yards to mils. This is accomplished by dividing the correction in yards by the range in thousands of yards ($26\div 10$). Thus, in the example, the correction is right 0-3, which is the whole number of mils closest to 2.6.

17C4. Motion of own ship

In the headings of range-table columns 13 and 16, neither true wind nor apparent wind is specified. If the gun were fired in a vacuum, the additional horizontal velocity imparted to the projectile by the motion of own ship would be equal in effect to equivalent target motion.

However, the gun is fired in air, which for purposes of this discussion is assumed to be motionless. Now, the movement of own ship through this still air creates a wind apparent to a person on the ship. This apparent motion of the wind is equal in speed but opposite in direction to ship motion. Its effect is partially to nullify the extra velocity imparted by own ship, for it acts on the projectile just as though it were an actual wind. Thus, the effect of a component of own-ship motion (column 14 of range table) is numerically equivalent to the effect of an equal component of

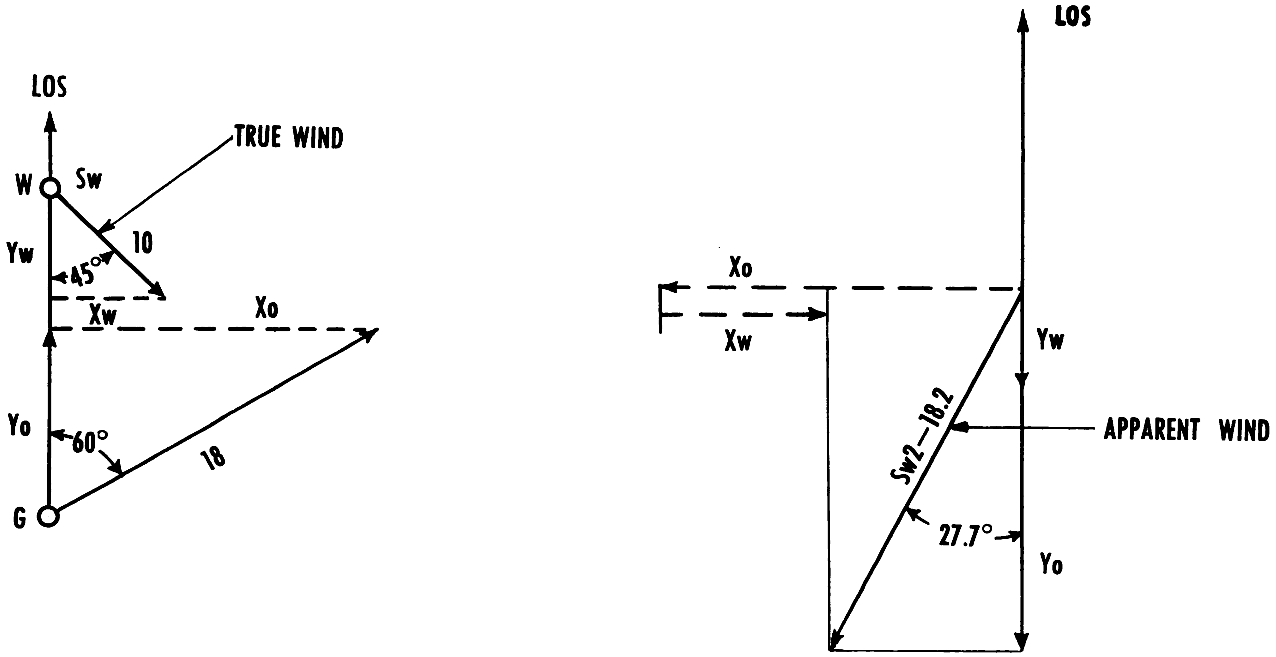

Figure 17C2.—Determination of apparent wind.

target motion (column 15 of range table) less the effect of an equal component of wind (column 13 of range table), as was pointed out in article 17B10.

If true wind is used, *gun* motion, from columns 14 and 17, will include the effect of the wind set up by own-ship motion (column 14=column 15−column 13, and column 17=column 18−column 16).

However, *apparent wind,* by definition, includes the effect of the wind set up by own ship's motion. Therefore, if apparent wind is used, the use of columns 14 and 17 for gun motion would then result in correcting for this wind effect twice. Therefore, when apparent wind is used, gun motion is the numerical equivalent of target motion, since wind set up by own ship's motion is incorporated in the apparent wind, and errors due to gun motion must be calculated using columns 15 for range and 18 for deflection. This is referred to as "treating gun motion as target motion." (If a mechanical device is used for computing the effects of gun and target motion, the two motions are combined and treated as one, using correction based on columns 15 and 18. Wind corrections must then be based on *apparent wind,* using columns 13 and 16.)

For an illustration assume that own ship and target are meeting head-on, each traveling at 10 knots, with no wind blowing (*i. e.,* wind speed is zero), and range is 10,000 yards. The problem of range using *true wind* is solved as follows: (See also appendix B, part 6.)

The errors in range are:			*Over*	*Short*
LOS				
1. T • Over 10	4. Target in LOS	Col. 15	124	*X*
	5. Wind in LOS	Col. 13	*X*	*X*
	6. Gun in LOS	Col. 14	46	*X*
2. W • Zero	7. Sum		170	0
			Drop	Add
3. G • Over 10	8. Computed gun ballistic correction in range		170	*X*

The problem of range errors using *apparent wind* under the same conditions is solved in this way: (See also appendix B, part 6.)

The errors in range are:			*Over*	*Short*
LOS 1. T Over 10	4. Target in LOS	Col. 15	124	*X*
	5. Wind in LOS	Col. 13	*X*	78
	6. Gun in LOS	Col. 15	124	*X*
2. W Short 10	7. Sum		248	78
			DROP	ADD
3. G Over 10	8. Computed gun ballistic correction in range		170	*X*

17C5. Use of apparent wind

Apparent wind is the vectorial resultant of the motion of the true wind and the reversed motion of the observing station (article 17C1). In the example given in article 17C2 (figure 17C1), the relative target bearing was 300°, own ship's speed 18 knots, and the true wind was from a direction of 255° relative, velocity 10 knots. The apparent wind is determined vectorially as illustrated in figure 17C2. The values of the components of this apparent wind are obtained by taking the algebraic sum of the true wind components, Xw and Yw, and the reversed own-ship components, of Xo and Yo.

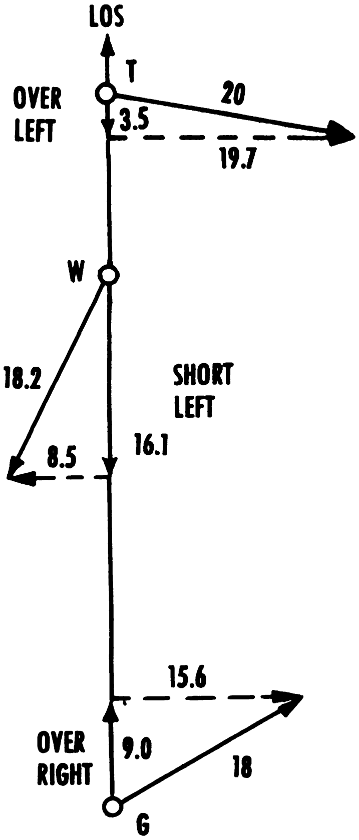

FIGURE 17C3.—Line-of-sight diagram (using apparent wind).

Figure 17C1 will now be revised to show apparent wind, the result appearing as figure 17C3. The combined components of gun and target motions in range are 9.0 + 3.5 = 12.5 knots, both components decreasing the range and causing an *over* error. In deflection the algebraic sum is 19.7 L − 15.6 R = 4.1 L. The net result is an error to the left.

The gun ballistic correction can now be recomputed using apparent wind: (See also appendix B, part 6.)

The errors in range are:		*Over*	*Short*
1. Powder temp. (article 17C3)		*X*	96
2. Erosion loss (article 17C3)		*X*	86
3. Air density (article 17C3)		*X*	215
4. Wind	Col. 13: $\frac{16.1}{10}\times 78=$	*X*	126
5. Gun & target	Col. 15: $\frac{12.5}{10}\times 124=$	155	*X*
6. Sum		155	523
		DROP	ADD
7. Computed gun ballistic correction in range		*X*	368

The errors in deflection are:	*Right*	*Left*
1. Drift	69	*X*
2. Wind Col. 16: $\frac{8.5}{10}\times 53=$	*X*	45
3. Gun & target Col. 18: $\frac{4.1}{10}\times 124=$	*X*	51
4. Sum	69	96
	LEFT	RIGHT
5. Computed gun ballistic correction in deflection	*X*	27

These results are practically identical with those obtained by the computation in article 17C3, indicating that the conclusions drawn in articles 17B8 and 17C4 are correct. The slight disparity between the results arises from the processes employed in the determination of values in the range table columns.

The rule for use of columns can be restated as follows:

	True Wind	*Apparent Wind*
Target motion . . .	Col. 15 and 18	Col. 15 and 18
Wind	Col. 13 and 16	Col. 13 and 16
Gun motion	Col. 14 and 17	Col. 15 and 18

17C6. Use of true quantities

In the conditions stated in the problem which was solved in articles 17C2 and 17C3, the firing ship's course was not given, nor was it needed, since relative bearings of target and wind as well as target angle were employed, thus furnishing all data necessary for the construction of the vector diagram.

In another type of problem a different statement of the conditions will be encountered. An example of this type will be solved as an illustration.

Example:

A ship, mounting 5"/38 caliber guns, steaming on course 225° (T) at speed 18 knots receives, during the night, information regarding the position of an enemy ship. The enemy is reported to be on course 265° (T), estimated speed 20 knots. It is predicted, by plotting, that at dawn the enemy will be in sight, at approximate range 10,000 yards, on bearing about 165° (T). Shortly before dawn the direction of the true wind is observed at 120° (T), velocity 10 knots. The average magazine temperature is 80° F., the velocity loss due to erosion from new-gun standard is 118 foot-seconds (or 18 f.s. from 2,500 f.s.) the surface air temperature is 52° F., and the barometer reading is 30".40.

Required:

It is required to compute the gun ballistic for this situation, in order to open fire immediately if the enemy is sighted as predicted.

Solution:

In order to construct a vector diagram when true directions and courses are given, it is necessary to keep in mind that the LOS now has a true direction. This can best be done by putting an arrow on the LOS extended and labeling it with its true direction (in this case 165°) as shown in figure 17C4.

Next lay off firing ship's course 225° (T), from which it is seen that the acute angle between the LOS and gun's vector is 60° (and that relative target bearing is 300°). Now lay off target course, 265° (T). It is evident that this course is 100° to the right of the LOS, and that the acute angle, *and target angle,* is 80 degrees. Finally the wind direction, 120°, is marked and the direction of the vector, as indicated,

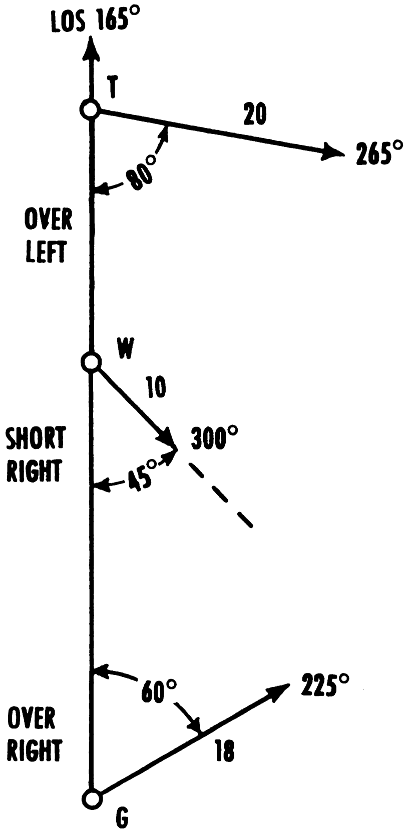

FIGURE 17C4.—Line-of-sight diagram (using true directions).

is thus 135°, to the right of the LOS, the acute angle being 45 degrees.

Constructing the vector diagram, figure 17C4, from the data stated in the foregoing paragraph shows that it is identical with figure 17C1. The other conditions (powder temperature, erosion loss, air temperature, and barometer) are also as stated in articles 17C2 and 17C3. Therefore the result obtained in article 17C3, ADD 368 YARDS, RIGHT 26 YARDS, is the gun ballistic correction in this case as well.

17C7. Definitions of various ballistic corrections

The discussion so far has been confined to the *gun ballistic* correction in range and deflection, for variations in the elements listed in article 17C3. These are the elements which will almost always be present in any practical case where the firing ship and target are moving, a wind is blowing, and corrections for the other variations from standard must be made.

Ballistic corrections for elements not listed in article 17C3 may also be required. These ballistic corrections will be defined, with very brief explanations of their characteristics and of the necessity for their use.

The *control ballistic correction* incorporates corrections which apply to the battery as a whole and which are caused by some artificiality in the method of control of the battery. In range and deflection the corrections that may be necessary are as follows:

The *sight-scale range-table correction.* It may occur that a gun is fitted with an obsolete range scale, although an up-to-date range table is available. (A modification in projectile design might be the cause of this disparity.) The sight-scale range-table correction will give the necessary correction to be applied to obtain a correct setting of the *old* sight scale at the given range. The correction is determined as follows: From the proper range table pick the angle of elevation, in minutes, corresponding to the desired range. Then enter the old range table, on which the sight scales are based, with this angle of elevation and note the corresponding range. The difference between this range and the desired range is the correction. If the range picked from the old range table is the greater, the correction is *plus.*

The *point-of-aim correction* usually arises in night firing or peculiar visibility conditions, when the point of aim must be one of the upper corners of the silhouetted target, while impact is desired at the center of the waterline. Another instance of this correction arises when a target is well beyond the horizon and the foretop (as an example) must be chosen as the point of aim, with impact desired at the center of the waterline. The method of determining this correction can readily be understood by reference to column 19 of the range table.

The *arbitrary ballistic correction,* also called "arbitrary correction to hit (ACTH)," is designed to correct for errors not otherwise accounted for, which have consistently been noted in past gunnery practices, where accurate data as to ranges, target course and speed, and other elements were available for an exhaustive post-firing analysis. After all errors which can be accounted for (such as errors in rangefinder ranges and in estimates of target course and speed) have been eliminated, there will probably remain a certain error in the point of fall for which no cause can be definitely assigned. When enough data have been obtained and analyzed to provide an accurate estimate of this quantity, it is used as an arbitrary ballistic correction.

The *correction for first salvo only* is necessitated by the fact that the initial round fired from a gun has a lower I. V., and therefore a shorter range, than succeeding rounds. This effect was at one time thought to be the result of the lower temperature of the bore; thus the correction has frequently and erroneously been known as "cold-gun correction." It is now known that the loss of velocity is caused by oil in the bore; thus the correction is needed only if the bore has been cleaned and oiled since the last previous shot was fired. The amount of the correction is derived from experience, as is the ACTH, but it must be considered and treated separately, inasmuch as it is applied for the first salvo only and then removed.

The *total ballistic correction* is the algebraic sum, in range and deflection, of the gun ballistic correction, the control ballistic correction (if any), and the arbitrary ballistic correction.

The *total ballistic correction for the first salvo* is the algebraic sum of the total ballistic correction and the correction for first salvo only.

The *initial ballistic correction* is a quantity applicable only when a gun (or battery of guns) is controlled by a fire control system that includes a computer or rangekeeper which computes some part of the ballistic corrections. Since almost all naval gunfire against targets is so controlled, this expression usually applies. It is defined as that part of the ballistic corrections not automatically compensated for by the fire control system.

Modern computing instruments handle many of the ballistic corrections which make up the total ballistic correction. Those corrections which are not so handled must be computed by gunnery personnel, and applied by hand to the rangekeeper. If, as is the case in all present rangekeepers, the correction for gun and target motions is continuously computed mechanicall and the correction is introduced automatically into the value of the range and deflection scale settings before they are sent to the guns, it is apparent that the same corrections must not again be made. In the various types of rangekeepers to be studied in the fire control chapters, the elements of the gun ballistic for which correction is made by the rangekeeper mechanism will differ with the type of rangekeeper. The corrections which must be computed and separately applied as component parts of the total ballistic correction will therefore vary with the type of rangekeeper which is supplying the guns with range and deflection settings. In practice the computed corrections are incorporated into one correction called initial ballistic correction.

17C8. Computation of initial ballistic correction

Figure 17C5* is the work sheet for the computation of the initial ballistic correction filled in for a typical example. (See also figure B2 in appendix B, part 6.) Although the values are representative, they are not taken from an actual firing. The lines across the top of the sheet marked "Battery," "Exercise," *etc.*, are for identification purposes, and the entries shown are self-explanatory.

Powder and erosion data. As item a, "Powder Index," enter on the sheet the powder index which appears on the powder card, thus identifying the powder used. Item b is "I. V. Erosion Data." Enter the initial velocity which is used as the basis from which velocity loss is computed. Its value may be found from the erosion-data section of the applicable range table. (It should be noted that this entry may not be the same as the I. V. for which the range table was prepared. See art. 17B4.) Item c is "Average Powder Temperature." Enter the average temperature of the magazine from which the powder is drawn. Item d, "Temperature Coefficient," is the number of foot-seconds change of I. V. for each 1° F. change of powder temperature. It will be considered as 2 foot-seconds for the example given (see art. 17B4). If more accurate information on temperature coefficient is to be used, it will be found in OP 1004, which is carried in the gunnery department library of the ship. Space is provided in item e for entering erosion data for the individual guns to be fired. (In the example given, one gun of each twin mount in a destroyer main battery is considered.) Entries are made for the gun numbers, (guns in multiple mounts are usually numbered with the mount number plus the letters, L, R, or C to indicate the position of the gun) the "pseudo equivalent service round," and bore enlargement or erosion-gage readings.

A review of chapter 5, section D, which discusses the manner of correcting I. V. loss due to erosion is required at this time, as is an understanding of the term "pseudo equivalent service round (PESR)." An equivalent service round has been previously defined as one which produces an amount of bore enlargement equal to that caused by a full-charge standard round. (Thus several reduced charges make up an equivalent service round.) The PESR is the number of equivalent service rounds corresponding to the last accurate measurement of bore enlargement.

When a gun is fired for the first time after star gaging, the PESR is not needed, since I. V. loss value may be obtained directly from the curve of I. V. loss against bore enlargement.

Suppose, however, that several firings have taken place since bore gaging. In this event the number of equivalent service rounds which have been fired *since* the last bore gaging are determined. This number of equivalent service rounds is then added to the PESR. With this total of service rounds a corresponding bore enlargement is picked off the ESR—bore-enlargement curve, and from this value the total I. V. loss may be obtained as before from the bore-enlargement curve.

If the temperatures of the various magazines from which the powder for individual guns is taken vary more than 2° F. from one another, entries should be made under the heading "Powder Temp. Corr." and the I. V. loss due to this effect combined with the I. V. loss due to bore enlargement. If this is done, line 1 shown on the sheet must be left blank. In this example it is considered that the magazine temperature of all the magazines is 80°, and therefore the entry under "Powder Temp. Corr.," item e, is zero, all loss of I. V. due to variation in powder temperature being accounted for under item 1 (*i. e.* 20 f. s.).

The important point to remember is that the effect of variation in I. V. due to change in powder temperature should not be corrected for twice. Since the entry under "Powder Temp. Corr." in the example is zero, the entries under column marked "I. V. loss F. S." will be the I. V. loss for each gun due only to bore enlargement, or 32, 34, and 34 foot-seconds respectively.

In 5"/38 caliber guns, erosion correctors are not provided at the individual guns. This means that an average I. V. loss (34 f. s. in this instance) will be used in line 2, and the notation "None provided" will be made under the heading "Erosion Corrector Setting, F. S." (If, however, as is the case in main-battery guns, individual erosion correctors are provided at the

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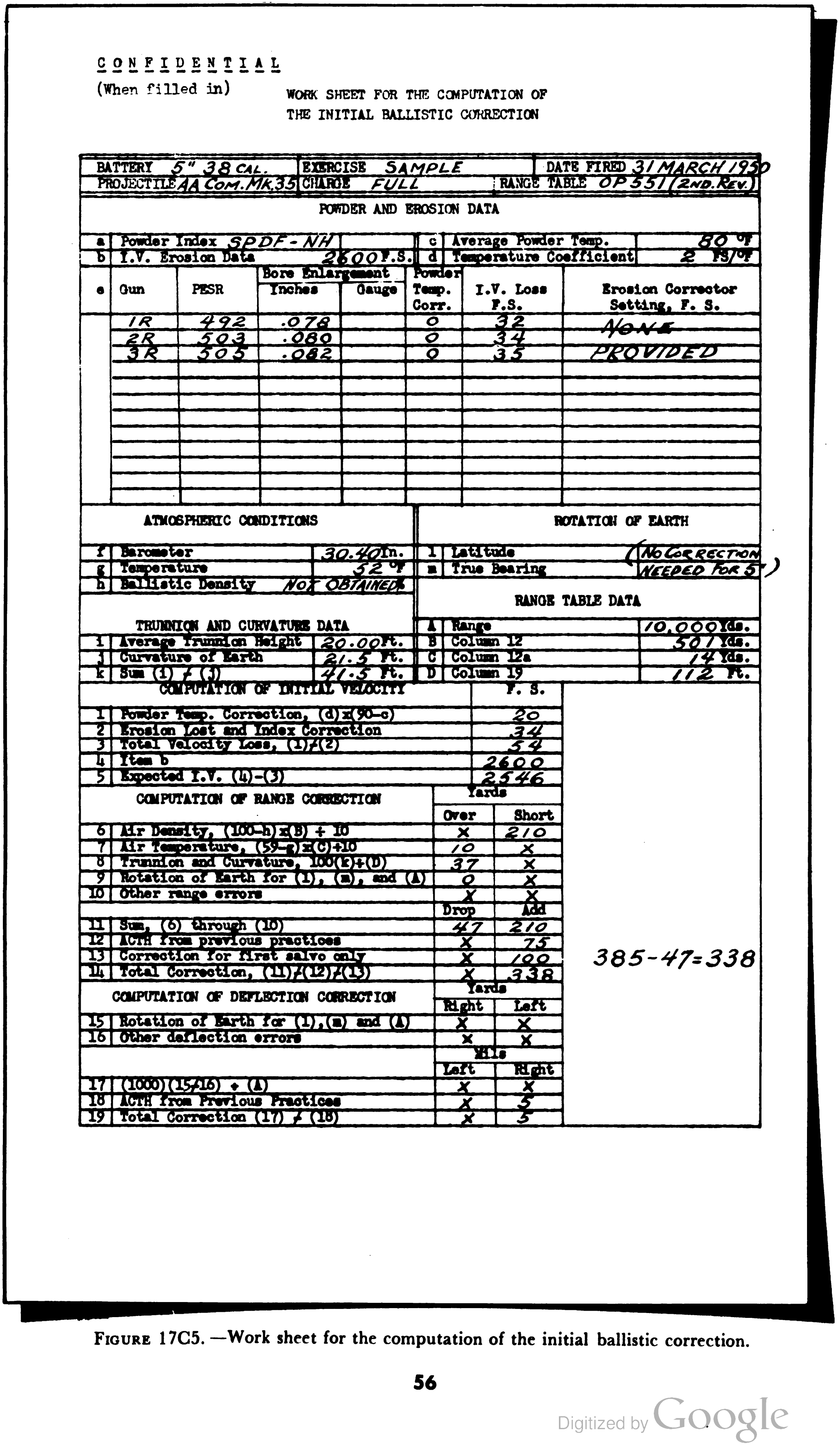
*The forms reproduced in figures 17C5 and 17D1, 2, and 3 are marked CONFIDENTIAL when filled in with data pertaining to an actual gunnery practice, and must be so treated. In this case, however, the data used are purely hypothetical.



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WORK SHEET FOR THE COMPUTATION OF
THE INITIAL BALLISTIC CORRECTION

BATTERY 5" 38 CAL.	EXERCISE SAMPLE	DATE FIRED 31 MARCH 1950
PROJECTILE AA COM. MK.35	CHARGE FULL	RANGE TABLE OP 551 (2ND. REV.)

POWDER AND EROSION DATA

a	Powder Index SPDF-NH		c	Average Powder Temp.	80 °F
b	I.V. Erosion Data	2600 F.S.	d	Temperature Coefficient	2 FS/°F

e	Gun	PESR	Bore Enlargement		Powder Temp. Corr.	I.V. Loss F.S.	Erosion Corrector Setting, F. S.
			Inches	Gauge			
	1R	492	.078		0	32	NONE
	2R	503	.080		0	34	
	3R	505	.082		0	35	PROVIDED

ATMOSPHERIC CONDITIONS

f	Barometer	30.40 In.
g	Temperature	52 °F
h	Ballistic Density	NOT OBTAINED

ROTATION OF EARTH

l	Latitude	(NO CORRECTION
m	True Bearing	NEEDED FOR 5")

TRUNNION AND CURVATURE DATA

i	Average Trunnion Height	20.00 Ft.
j	Curvature of Earth	21.5 Ft.
k	Sum (i) + (j)	41.5 Ft.

RANGE TABLE DATA

A	Range	10,000 Yds.
B	Column 12	501 Yds.
C	Column 12a	14 Yds.
D	Column 19	112 Ft.

	COMPUTATION OF INITIAL VELOCITY	F. S.
1	Powder Temp. Correction, (d) x (90–c)	20
2	Erosion Lost and Index Correction	34
3	Total Velocity Loss, (1) + (2)	54
4	Item b	2600
5	Expected I.V. (4)-(3)	2546

	COMPUTATION OF RANGE CORRECTION	Yards	
		Over	Short
6	Air Density, (100-h) x (B) ÷ 10	X	210
7	Air Temperature, (59-g) x (C) ÷ 10	10	X
8	Trunnion and Curvature, 100(k) ÷ (D)	37	X
9	Rotation of Earth for (l), (m), and (A)	0	X
10	Other range errors	X	X
		Drop	Add
11	Sum, (6) through (10)	47	210
12	ACTH from previous practices	X	75
13	Correction for first salvo only	X	100
14	Total Correction, (11) + (12) + (13)	X	338

385-47=338

	COMPUTATION OF DEFLECTION CORRECTION	Yards	
		Right	Left
15	Rotation of Earth for (l), (m) and (A)	X	X
16	Other deflection errors	X	X
		Mils	
		Left	Right
17	(1000)(15+16) ÷ (A)	X	X
18	ACTH from Previous Practices	X	5
19	Total Correction (17) + (18)	X	5

FIGURE 17C5.—Work sheet for the computation of the initial ballistic correction.

guns and compensation for gun erosion is made both at the guns and in the rangekeeper, the column marked "Erosion Corrector Setting, F. S." would have the entry zero opposite the least eroded gun of the battery. Entries for the other guns would be the velocity loss in excess of that for the least eroded gun.)

Atmospheric conditions. Item f is the barometer reading in inches, and item g is the temperature in degrees Fahrenheit. Both are surface readings taken from the ship's instruments. Item h, "Ballistic Density," is to be left blank unless it has been determined from actual measured data aloft or from an estimate made by an experienced aerologist.

Trunnion and curvature data. It has been brought out that the angle of elevation to be set on a gun is normally applied from the LOS. When the target cannot be seen and no LOS is available (which often happens during shore bombardment), the angle of elevation is applied above the horizontal plane. This use of the horizontal plane gives rise to two additional errors at long ranges in surface fire—those caused by (1) the earth's curvature and (2) trunnion height. Although the solution is correct for a target which lies in the horizontal plane tangent to the earth at own ship's position, it will be in error if the earth's curvature causes the target to drop below that horizontal plane, or if the fact that the guns are located high above the waterline causes the whole trajectory to be raised by the amount of such trunnion height above that horizontal plane. Therefore if the guns are laid with respect to a horizontal plane a correction is used, and it is necessary to fill in items i and j. Item i is the average height of the gun trunnions above the waterline. Its value can be obtained by reference to ship's drawings. Data for item j can be obtained from an ordnance circular letter which gives curvature of the earth for various values of range. Item k is self-explanatory.

Rotation of earth. This correction is omitted for guns of 5-inch and smaller caliber. When it is used, the value is to be found in a table which is entered with item l, the latitude, to the nearest degree, item m, the true bearing of the target, and item A, the range.

Range-table data. The best estimate of the present range to the target when the opening salvo is to be fired, is entered as item A. Using the value of range, item A, as an argument, items B, C, and D, columns 12, 12a and 19, respectively, are copied directly from the range table.

Computation of initial velocity. Since, as stated above, the powder-magazine temperature for the three guns was the same, line 1 will be filled in this example. The algebraic sign from the formula as given is used. (i. e., the sign will be + in this instance, since item c (80°) is less than 90). This is because, as will be noted in connection with line 3, velocity *loss* rather than correction for this loss is being computed. In line 2 is entered 34, the average foot-second loss of the three guns, determined from the column "I. V. Loss F. S.," in item e. If compensation for erosion is made both in the computing instrument and at the guns, the value appearing in line 2 would still be "I. V. Loss F. S." taken from item e, but would be the I. V. loss of the least eroded gun rather than an average value. The sign as given in this case, and almost always, is positive. In line 4 enter item b, 2,600 foot-seconds. The value which appears in line 5 is an algebraic sum. It is the expected initial velocity of the projectile and is set into the rangekeeper or computer.

Computation of range correction. The entry in line 6 has in this case been determined from the nomogram in part 1 of appendix B. (When the value of ballistic density as discussed in connection with item h has been entered as a percentage of standard density, which is considered as 100 percent, the formula in line 6 will give the proper value for entry in that line. If h is greater than 100, enter in the "short" column, if less than 100 enter in the "over" column.) Line 7 is the range correction for variation of air temperature from standard. If the algebraic sign from the formula is plus, entry is made in the "over" column; if minus, in the "short" column. The entry for line 8 (trunnion and curvature data), is *always* "over." This correction is used only when the guns are being fired with respect to a horizontal plane (as in shore bombardment where the target cannot be seen), instead of with respect to a line of sight; in the example, the former is considered to be the case.

Although no correction is made for rotation of the earth for 5-inch and smaller-caliber guns, a brief explanation is made here regarding the entry in line 9. Range tables for guns which require this entry have a table which, when entered with the arguments, latitude (item l) and range (item A), and true bearing of target (item m), will give the value of correction to be entered in line 9. If the sign is plus, enter in the "over" column; if minus in the "short" column. Line 10, "other range errors," is provided to account for certain range errors which are not normally encountered. A range error incident to the rangekeeper (computer) not being designed to compute data for the projectile which is to be fired, would properly be entered on this line. (Computations which involve the present range, expected I. V., and values taken from the range tables both (1) for the projectile being fired and (2) for the projectile on which the computer was designed, enter into determination of such an error and will not be detailed here.) Also, the automatic compensation in a rangekeeper (computer) made for certain elements is, under certain conditions, an approximation. Under such conditions, an appreciable error may result and should be accounted for in line 10. Applicable publications are available to enable evaluation of this error. In the given example the value of "other range errors" is considered to be zero. In line 12, ACTH (arbitrary correction to hit), is entered the correction in range which has been evaluated from previous firings, representing the value of consistently unaccountable errors. The entry for line 13 has been explained in section 17C7.

Line 14 is self-explanatory. It is important to note that it is a *correction* rather than an *error*. It will be noted that this is taken care of by changing column headings to read "corrections" rather than "errors" after line 10. The correction thus derived represents that part of the initial ballistic correction in range which is not accounted for in the rangekeeper setting made in accordance with line 5. It will be noted that in the example the correction, as stated, can be used only for the first salvo. Succeeding salvos will take a correction of ADD 238 YARDS instead of 338 yards, as item 13 will no longer apply. This correction, in most fire control systems, is entered into the rangekeeper or computer as a *range spot*.

Computation of deflection correction. Line 15, correction for "rotation of earth," is zero in this example, since it is omitted for 5-inch and smaller-caliber guns. When used, the proper value is found in a table in the back of the range table similar to the one discussed in connection with range correction. Line 16, "other deflection errors," is governed by the same consideration as line 10. In general, if the rangekeeper (computer) is not designed for the projectile to be fired, the deflection difference will be so small that it can be neglected. However, an investigation should be made to verify this. In the example no other deflection errors are considered present, and the entry in line 16 is zero.

The total correction in deflection, line 19, is the sum of line 17 (which converts errors given on line 15 and 16 in yards to correction in mils, and line 18, which value is arrived at in the same manner as was described for line 12. The total correction in deflection constitutes the initial ballistic correction in deflection; it is entered into the computing instrument as a *deflection spot*.

D. Target-Practice Post-Firing Analysis

17D1. Gunnery Sheet 4

A complete analysis is normally made after each target-practice firing, covering all conditions and matters affecting the practice. Such an analysis will determine errors and, when compared with similar firings by other vessels, will furnish valuable information affecting design of material and improvement of both ordnance material and gunnery procedures. One important goal of post-firing analyses, and the one of primary interest at this time, is determination of the *arbitrary correction to hit,* which was defined in section 17C7. In order that no factors which affect the ACTH be overlooked, standard procedure has been prescribed to determine its value, and standard forms to record the results are used.

The standard form used to compute and record the arbitrary correction to hit in both range and deflection is Gunnery Sheet 4, shown in figures 17D2 and 17D3. This sheet accompanies the post-firing analysis report and forms a part of the permanent record of a target-practice firing. A work sheet, figure 17D1, is used in conjunction with the finished smooth Sheet Four. See footnote on page 55.

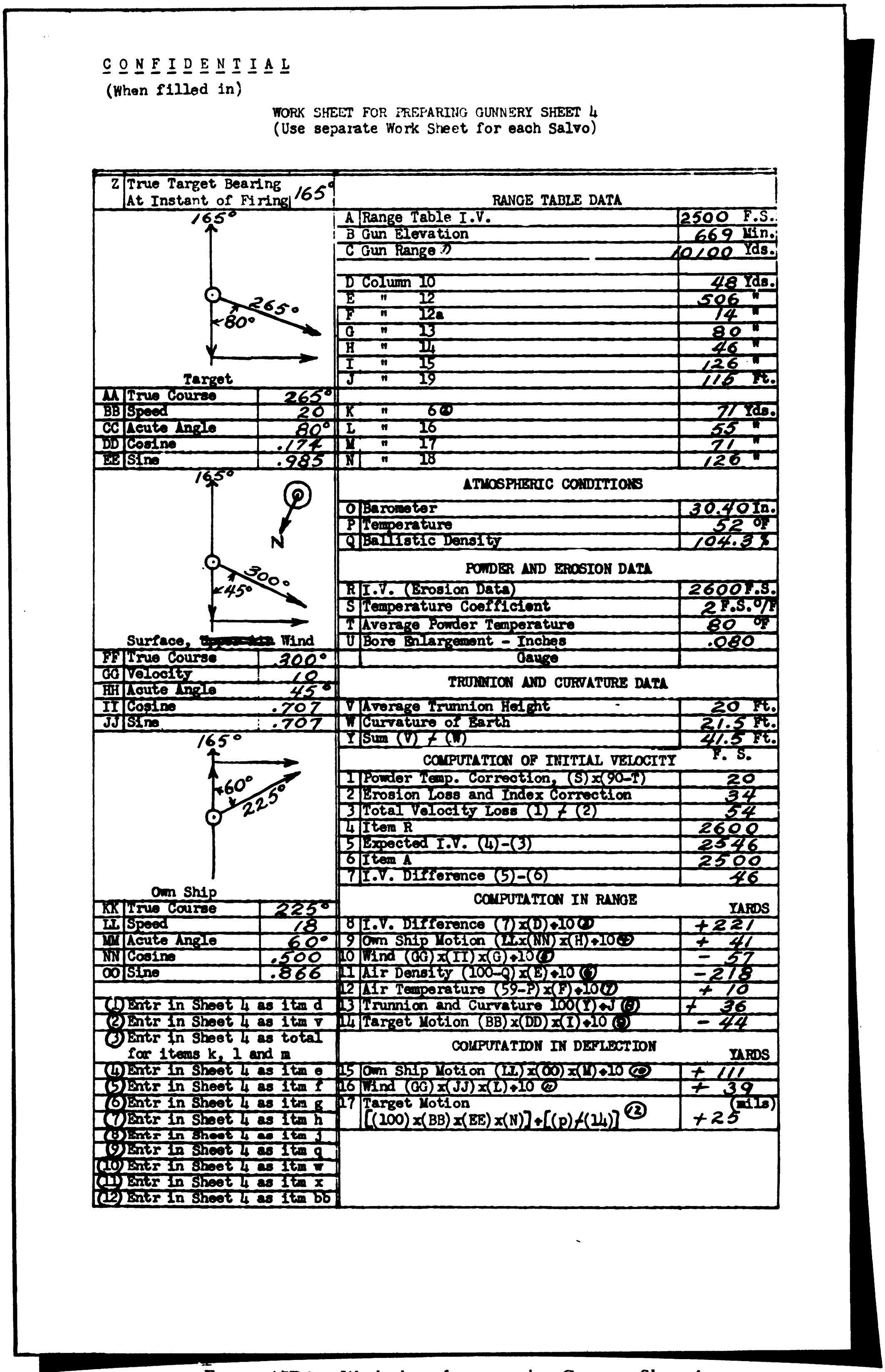
17D2. Preparation of work sheet

The following is an example for the first salvo of a hypothetical target practice, starting with computations and filling in data on the work sheet. Refer to figure 17D1. (See also figure B3 in appendix B, part 6.)

Range-Table Data

Item A. Enter the I. V. for which the range table is computed. In accordance with the range table in appendix C, part 2, an entry of 2,500 foot-seconds is made on this line.

Item B. In this space should be entered the actual angle of elevation of the gun *above the horizontal plane* at the time of firing. The computations needed for the determination of this value will depend on whether the gun was fired with respect to a line of sight or with respect to the horizontal, and upon the method which the particular fire control system uses to make certain corrections, such as whether erosion correctors are located at the gun or in the computer. In the example given the following conditions are assumed: (1) the sight-angle counter read 2,669 minutes, (2) the guns were positioned with respect to the horizontal plane rather than the line of sight, and (3) no erosion correctors were used at the guns. The entry in item B is therefore 2,669 − 2,000 minutes, or 669 minutes, since 2,000 minutes represents zero sight angle. (The value 669 minutes to which the gun was elevated is the angle



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WORK SHEET FOR PREPARING GUNNERY SHEET 4
(Use separate Work Sheet for each Salvo)

Z	True Target Bearing At Instant of Firing	165°

165°
265°
80°

Target

AA	True Course	265°
BB	Speed	20
CC	Acute Angle	80°
DD	Cosine	.174
EE	Sine	.985

165°
N
300°
45°

Surface, ~~Upper Air~~ Wind

FF	True Course	300°
GG	Velocity	10
HH	Acute Angle	45°
II	Cosine	.707
JJ	Sine	.707

165°
60°
225°

Own Ship

KK	True Course	225°
LL	Speed	18
MM	Acute Angle	60°
NN	Cosine	.500
OO	Sine	.866

① Entr in Sheet 4 as itm d
② Entr in Sheet 4 as itm v
③ Entr in Sheet 4 as total for items k, l and m
④ Entr in Sheet 4 as itm e
⑤ Entr in Sheet 4 as itm f
⑥ Entr in Sheet 4 as itm g
⑦ Entr in Sheet 4 as itm h
⑧ Entr in Sheet 4 as itm j
⑨ Entr in Sheet 4 as itm q
⑩ Entr in Sheet 4 as itm w
⑪ Entr in Sheet 4 as itm x
⑫ Entr in Sheet 4 as itm bb

RANGE TABLE DATA

A	Range Table I.V.	2500 F.S.
B	Gun Elevation	669 Min.
C	Gun Range ①	10100 Yds.
D	Column 10	48 Yds.
E	" 12	506 "
F	" 12a	14 "
G	" 13	80 "
H	" 14	46 "
I	" 15	126 "
J	" 19	116 Ft.
K	" 6 ②	71 Yds.
L	" 16	55 "
M	" 17	71 "
N	" 18	126 "

ATMOSPHERIC CONDITIONS

O	Barometer	30.40 In.
P	Temperature	52 °F
Q	Ballistic Density	104.3 %

POWDER AND EROSION DATA

R	I.V. (Erosion Data)	2600 F.S.
S	Temperature Coefficient	2 F.S.°/F
T	Average Powder Temperature	80 °F
U	Bore Enlargement - Inches	.080
	Gauge	

TRUNNION AND CURVATURE DATA

V	Average Trunnion Height	20 Ft.
W	Curvature of Earth	21.5 Ft.
Y	Sum (V) + (W)	41.5 Ft.

	COMPUTATION OF INITIAL VELOCITY	F. S.
1	Powder Temp. Correction, (S)x(90-T)	20
2	Erosion Loss and Index Correction	34
3	Total Velocity Loss (1) + (2)	54
4	Item R	2600
5	Expected I.V. (4)-(3)	2546
6	Item A	2500
7	I.V. Difference (5)-(6)	46

	COMPUTATION IN RANGE	YARDS
8	I.V. Difference (7)x(D)÷10 ③	+221
9	Own Ship Motion (LL)x(NN)x(H)÷10 ④	+ 41
10	Wind (GG)x(II)x(G)÷10 ⑤	− 57
11	Air Density (100-Q)x(E)÷10 ⑥	−218
12	Air Temperature (59-P)x(F)÷10 ⑦	+ 10
13	Trunnion and Curvature 100(Y)÷J ⑧	+ 36
14	Target Motion (BB)x(DD)x(I)÷10 ⑨	− 44

	COMPUTATION IN DEFLECTION	YARDS
15	Own Ship Motion (LL)x(OO)x(M)÷10 ⑩	+ 111
16	Wind (GG)x(JJ)x(L)÷10 ⑪	+ 39
17	Target Motion [(100)x(BB)x(EE)x(N)]÷[(p)+(14)] ⑫	(mils) +25

FIGURE 17D1.—Work sheet for preparing Gunnery Sheet 4.

of elevation corresponding to the range of 10,000 yards, at which the practice was to be fired, plus the total ballistic correction.)

The manner of correcting for all conditions which might vary from those which have been assumed for the given example is not covered in detail here. One such example, however, is: had the guns been positioned relative to the line of sight instead of the horizontal, as assumed, it would be necessary to find the curvature of the earth for the range from a suitable table. To this curvature would be added the trunnion height of the gun. Then the angle is found, the tangent of which is:

$$\frac{\text{curvature of earth} + \text{trunnion height}}{\text{range in feet}}$$

The value of this angle would then be subtracted from the value 2,669 minutes to obtain the actual angle of elevation above the horizontal. The important point to note is that item B is actual gun elevation *above the horizontal plane.*

Item C is the range-table value corresponding to item B. In the example a range-table value of 10,100 yards corresponds to an angle of elevation of 669 minutes.

Items D through N are taken directly from the proper columns of the range table, entering with the value of item C. Tabulations are made to the nearest yard. Note that item K is entered on Sheet 4 as item V. (Item F does not appear in some range tables. Disregard the correction for variation in air temperature if this is the case.)

Atmospheric Conditions

Items O and P, 30.40 inches and 52° F. in the example, are surface readings from ship's instruments.

Item Q. As explained in article 17B6, data for this item may be determined from measured data aloft or from an estimate made by an experienced aerologist. In this example, an entry assumed to be from such a source has been made. If such data are not available, this item is left blank and a nomogram is used for item 11 below.

Powder and Erosion Data

Item R is the initial velocity used as a basis for velocity loss. In this example it is the nominal I. V. of a new 5″/38 caliber gun using a full charge, 2,600 foot-seconds. Item R does not have to be the same as item A. For the reasons pointed out in article 17B3, the range table is based on an I. V. of 2,500 instead of on the nominal initial velocity.

Item S in the example is taken as 2 foot-seconds for each degree Fahrenheit. For an actual practice, a more accurate temperature coefficient should be used as determined from OP 1004 or from the erosion data.

Item T is normally the average temperature of the magazines from which the powder is drawn, in this case taken as 80 degrees Fahrenheit.

Item U. Here is recorded the bore enlargement in inches obtained in the same manner as described above in connection with the work sheet for the computation of the initial ballistic correction. In the example, the figure is 0.08 inches.

Trunnion and Curvature Data

Item V, the average trunnion height above sea level, is obtained from the ship's drawings.

Item W is obtained from a table, entering with the argument range. Such a table is contained in *Ordnance Circular Letter F8–43.* If the letter is not available, the value can be computed from the dip table in Bowditch.

Target, Wind, and Own-Ship Data

The line-of-sight diagram is covered in detail in section 17C. Three spaces are provided on the work sheet for indicating by vectors the target, wind, and own-ship motion relative to the true bearing of the target. In each case, the line already drawn represents true target bearing. The direction north, relative to true target bearing, is indicated by drawing an arrow through the dot in the circle in the upper right-hand corner of the wind square. The acute angles CC, HH, and MM, are the acute angles between direction of motion of target, wind, and own ship respectively, and the true bearing of the target at the instant of firing. Values of the cosine and sine may be obtained from mathematical tables of trigonometric functions (appendix D), and tabulated to three places.

Target data. Motion of the target in no way affects the trajectory or flight of the projectile. During time of flight, however, if the target is under way it moves from the position it occupied at the instant of firing. Target motion toward own ship will decrease the range, while target motion away from own ship will increase the range. If the target moves across the line of sight toward the right, it will change position to the left. In the example target motion, true course 265°, speed 20 knots, is shown with respect to the line of true target bearing. Direction of motion is toward own ship (−) and to the right (+).

Wind data. Either "surface" or "upper air" should be crossed out. The upper-air (ballistic) wind should be used when the maximum ordinate exceeds 3,000 feet and accurate aloft winds are available. At other times surface wind is used. In the example, as indicated by reference to column 8 of the range table, the maximum ordinate is less than 3,000 feet.

Since FF is true course of the wind, the wind vector will be drawn "down wind." The effects of wind for the example shown, true course 300°, velocity 10 knots, will cause a *short* (−) and a *right* (+) error.

Own-ship data. The motion of own ship imparts component horizontal velocities to the projectile in proportion to the components of own-ship motion in and across the line of fire. In the example the vector representing own-ship motion with respect to the true target bearing, true course 225°, speed 18 knots, indicated an *over* (+) and a *right* (+) error.

Computation of Initial Velocity

Item 1 is the error in I. V. due to a variation in powder temperature from 90 degrees Fahrenheit. It should be noted that if temperature is greater than 90° F., the sign is *minus,* even though an increase in range results. The reason for this is not obvious, but a study of item 1 in conjunction with items 2 and 3 will clarify it. Item 2 is always a velocity *loss* (since erosion never increases the I. V.). The effect of a powder temperature above 90° F. will reduce this loss, while a powder temperature below 90° F. will increase the loss. Item 3, which is the algebraic sum of items 1 and 2, will therefore be of the correct sign if powder temperature correction is treated as described above. Should item 3 come out with a minus sign, it would indicate a velocity gain. Such a case could occur with a new gun when firing powder from a magazine the temperature of which was above 90 degrees Fahrenheit. This will rarely happen.

Item 2. The entry 34 foot-seconds represents the I. V. loss due to a bore enlargement of 0.080 inch. The manner in which this value is obtained was discussed in articles 17C8, 5D5, and 5D6.

Items 4, 5, 6, and 7 are self-explanatory.

Computation in Range

The computation in range for *items 8 through* 14 is carried out in accordance with the instructions on the work sheet. It is important that the proper signs be used, so that, when these items are transferred to Sheet 4 in accordance with the instructions in the lower left-hand corner of the work sheet, the correct value of expected range will result.

If ballistic density has not been obtained and entered in item Q, the value to be entered as item 11 will be obtained directly from the nomogram instead of from the stated formula.

Computation in Deflection

Items 15, 16, and 17 are filled in with data worked out in accordance with the instructions contained on the work sheet. The proper signs can be determined by reference to the vector diagrams. The value p, used in the formula for item 17, represents the navigational range at the instant of firing, as recorded on Sheet 4. This is the most accurate value of range that can be obtained at the time of the post-firing analysis. As will be noted in the formula, it must be adjusted for target motion by use of item 14.

Computation of ACTH

After completion of the work sheet for Sheet 4, actual computation of the sheet will be undertaken. Refer to figures 17D2 and 17D3. (See also figures B4 and B5 in appendix B, part 6.) Items 1 through 12, in the lower left-hand corner of the work sheet, contain instructions for transferring entries from the work sheet to Sheet 4.

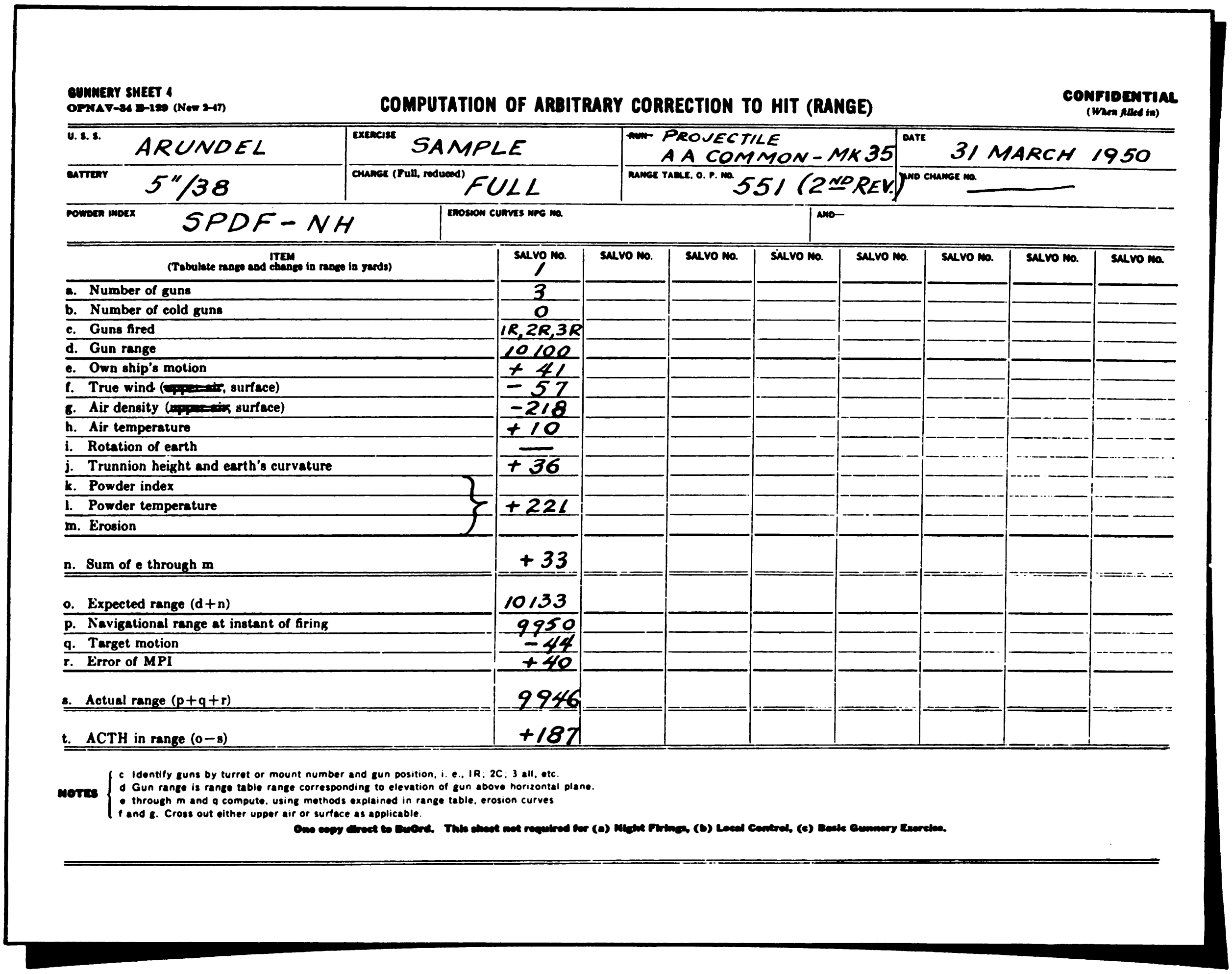
17D3. Computation of arbitrary correction to hit (range)

The first lines on Sheet 4 are for identification purposes and in general are self-explanatory. The heading of the space named "run" should be changed to "projectile" and the latter identified by type, mark, and modification.

Item a, "number of guns," refers to the number of guns actually fired. If, for example, a six-gun salvo was intended but due to a casualty only five guns fired, the proper entry is 5.

In *item b,* "number of cold guns" is entered the number of guns firing their initial round since last cleaned and oiled. In the example it is considered that the practice for which the Sheet 4 is being worked out was not the first practice fired that day. The entry here is therefore zero (the correction for the first salvo has been discussed in article 17C7). Had "cold guns" been used in the practice and such a correction applied, item C of the work sheet (and item d of Sheet 4) would then contain this correction, and the range-table values for items C through N of the work sheet would correspond to the corrected range. As an example, if a first-salvo correction of +200 yards were used, item C would then read 10,300 yards and the gun elevation, item B, and also items D through N, would have had different values from those shown.

Item c, "guns fired," identifies guns by turret or mount number and gun position. The right guns of



GUNNERY SHEET 4
OPNAV-34 B-129 (New 2-47)

COMPUTATION OF ARBITRARY CORRECTION TO HIT (RANGE)

CONFIDENTIAL
(When filled in)

U. S. S. ARUNDEL
EXERCISE SAMPLE
~~RUN~~ PROJECTILE A A COMMON - MK 35
DATE 31 MARCH 1950
BATTERY 5"/38
CHARGE (Full, reduced) FULL
RANGE TABLE, O. P. NO. 551 (2ND REV.)
AND CHANGE NO. ——
POWDER INDEX SPDF - NH
EROSION CURVES NPG NO.
AND—

ITEM (Tabulate range and change in range in yards)	SALVO NO. 1	SALVO NO.	SALVO NO.	SALVO NO.	SALVO NO.	SALVO NO.	SALVO NO.	SALVO NO.
a. Number of guns	3							
b. Number of cold guns	0							
c. Guns fired	1R, 2R, 3R							
d. Gun range	10100							
e. Own ship's motion	+ 41							
f. True wind (~~upper air~~, surface)	− 57							
g. Air density (~~upper air~~, surface)	−218							
h. Air temperature	+ 10							
i. Rotation of earth	——							
j. Trunnion height and earth's curvature	+ 36							
k. Powder index								
l. Powder temperature	+ 221							
m. Erosion								
n. Sum of e through m	+ 33							
o. Expected range (d+n)	10133							
p. Navigational range at instant of firing	9950							
q. Target motion	− 44							
r. Error of MPI	+ 40							
s. Actual range (p+q+r)	9946							
t. ACTH in range (o−s)	+187							

NOTES
c Identify guns by turret or mount number and gun position, i. e., 1R; 2C; 3 all, etc.
d Gun range is range table range corresponding to elevation of gun above horizontal plane.
e through m and q compute, using methods explained in range table, erosion curves
f and g. Cross out either upper air or surface as applicable.

One copy direct to BuOrd. This sheet not required for (a) Night Firings, (b) Local Control, (c) Basic Gunnery Exercise.

FIGURE 17D2.—Gunnery Sheet 4 (front).

mounts 1, 2, and 3 were fired in the hypothetical practice which is being considered.

Items d, e, f, g, and h are obtained from the work sheet. Entering values with the proper sign is important.

Item i is zero in the example, since, as was pointed out in article 17C8, this correction is omitted for guns of 5-inch and smaller caliber.

Items k, l, and m. The total for these items is combined in the computations on the work sheet. Although the computed I. V. of 2,546 foot-seconds would cause a decrease in range from values taken from a 2,600 foot-second range table, it does cause an increase in the range values taken from the 2,500 foot-second range table which is being used in computing values in the example. Therefore, the sign is *plus* for this entry of 221 yards.

Item o, the expected range, is the gun range corrected for all known variations from standard range-table conditions which affect the projectile in flight, plus trunnion height and earth's curvature. It should be noted that the target motion does not enter into this computation, because the value of expected range applies to the point of fall of the projectiles and is to be used for comparison with the actual range to the point of fall.

Item p is the navigational range at the instant of firing. The most accurate and carefully calibrated radar should be used to obtain this figure. If no more accurate data are available, the present range of the computer solution should be entered.

Item q is obtained from the work sheet, using care in selecting the proper sign. Since in the example the target is closing, the range will decrease during the time of flight of the projectile.

Item r, the error of MPI, represents the actual difference between the position of the target at the instant of the fall of the projectiles and the mean point of impact of the several shots. The precise definition of MPI, *mean point of impact,* and the method of computing it from the points of impact of the several individual shots, are discussed in chapter 18.

For this use in post-firing analysis, the best available data on the points of fall of individual projectiles should be used. When a camera party is available, these best data are obtained by triangulation of aerial photographs. *Overs* carry the (+) sign; *shorts,* (−). An arbitrary value of +40 for error of MPI is used in figure 17D2.

Item s, it will be apparent by inspection, represents the actual range, to the point of fall, of the projectiles fired.

Item t, therefore, represents the otherwise unaccounted-for errors, the average value of which for several complete practices may be used as ACTH in range.

17D4. Computation of arbitrary correction to hit (deflection)

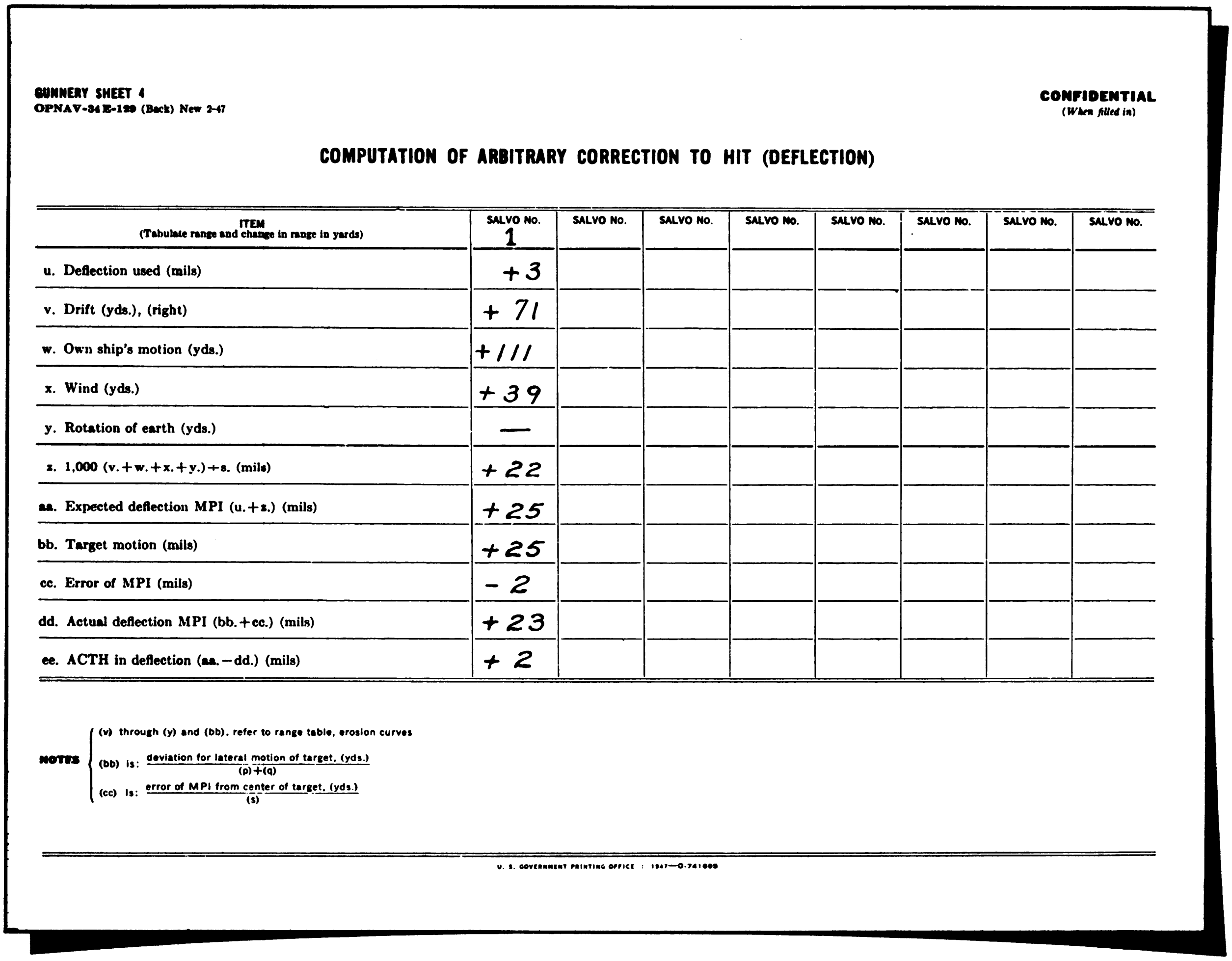
Item u is the difference between the midpoint of the deflection scale and the actual scale reading. It is the number of mils between the plane through the LOS and the plane through LOF at the instant the gun was fired. The sign is (+) if the scale reading is to the right of the midpoint and (−) if to the left. In the example the scale reading was 503.

Items v, w, and x—71, 111, and 39 yards, respectively in this example—are taken from the work sheet. The proper sign is important.

Item y is similar to *item i* and its value is zero in this example for the reason previously given.

Item z, it will be noted, includes a conversion from yards to mils at the actual range.

Item aa, the expected deflection, consists of the



GUNNERY SHEET 4
OPNAV-34E-129 (Back) New 2-47

CONFIDENTIAL
(*When filled in*)

COMPUTATION OF ARBITRARY CORRECTION TO HIT (DEFLECTION)

ITEM (Tabulate range and change in range in yards)	SALVO NO. 1	SALVO NO.	SALVO NO.	SALVO NO.	SALVO NO.	SALVO NO.	SALVO NO.	SALVO NO.
u. Deflection used (mils)	+3							
v. Drift (yds.), (right)	+ 71							
w. Own ship's motion (yds.)	+111							
x. Wind (yds.)	+39							
y. Rotation of earth (yds.)	—							
z. 1,000 (v.+w.+x.+y.)÷s. (mils)	+22							
aa. Expected deflection MPI (u.+z.) (mils)	+25							
bb. Target motion (mils)	+25							
cc. Error of MPI (mils)	−2							
dd. Actual deflection MPI (bb.+cc.) (mils)	+23							
ee. ACTH in deflection (aa.−dd.) (mils)	+2							

NOTES
(v) through (y) and (bb), refer to range table, erosion curves
(bb) is: $\frac{\text{deviation for lateral motion of target, (yds.)}}{(p)+(q)}$
(cc) Is: $\frac{\text{error of MPI from center of target, (yds.)}}{(s)}$

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FIGURE 17D3.—Gunnery Sheet 4 (rear).

deflection used, corrected for drift and for those variations from standard range-table conditions which affect the projectile while it is in the air. This item serves the same purpose in deflection as item o in range.

Item bb is obtained from the work sheet.

Item cc is the error of the MPI in mils, obtained by photo triangulation or observation. If the MPI is right of the target the sign is (+), if left (−). In the example, the error of the MPI was 2 mils left.

Item dd is the actual deflection of the MPI in mils. It is the perpendicular distance (converted to mils) from the vertical plane through the line of sight to the mean point of impact. This item is the deflection equivalent of item s above.

Item ee, the ACTH in deflection, is obtained by subtracting item aa from item dd. Like item t in range, it represents the errors otherwise unaccounted for. These two values ACTH in range and deflection represent the two values which, as stated above, are to be found through the processes of post-firing analysis.

Chapter 18

SPOTTING

A. Laws of Probability in Their Effect on Gunfire and on Spotting

18A1. Requirement

As the study of exterior ballistics has indicated, not all the factors which affect the flight of a projectile can be precisely evaluated in advance of firing. Even with the best fire control equipment available, experienced gun crews, and efficient fire control personnel, the opening shots may not hit the target. It is therefore necessary to apply corrections (or *spots*) to the initial firing data to bring the shots on the target. The corrections are applied to gun-laying data for subsequent rounds fired. This technique is called spotting.

18A2. Definitions

The following definitions relate to gunfire and to terms used in connection with spotting.

Salvo. A salvo consists of one shot or more shots fired simultaneously by the same battery at the same target.

Slow fire. Slow fire is that type of fire in which the fire is deliberately delayed to allow for the application of spots or to conserve ammunition.

Rapid fire. Rapid fire is that type of fire which is not delayed for purposes of applying corrections.

Continuous fire. Continuous fire is the firing of each gun without regard for the readiness of other guns in the battery. No real salvos exist in this type of fire, but a spotter may treat those shots which fall during an interval of a few seconds as a salvo for his purposes.

The MPI. The mean point of impact (MPI) is the geometric center of the points of impact of the various shots of a salvo, excluding wild shots.

Wild shot. A wild shot is a shot with an abnormally large dispersion in range, or deflection, or both.

In general the dispersion of a wild shot is too great to have been caused by any of the accidental errors mentioned in article 18A3, and is considered as due to a *mistake* rather than an error. For example, a powder bag loaded with its ignition pad forward is a mistake and will probably cause excessive dispersion. Again, in pointer control, if a sight setter were to set a range of 15,000 yards instead of the correct range, 10,500 yards, the results would be considered a wild shot. In director control, an error in the train parallax correction or the roller-path inclination setting, both of which are applied at the individual turret, may have a similar result, as will become clear when these corrections are explained in chapters 19 and 21.

Pattern. The pattern of a salvo in range is the distance measured parallel to the line of fire between the shortest shot of the salvo and the longest shot, excluding wild shots. In deflection it is the distance measured at right angles to the line of fire between the shot falling or bursting farthest right and the shot falling or bursting farthest left, excluding wild shots.

Dispersion. The dispersion of a shot is the distance of the point of impact of that shot from the MPI of the salvo. Dispersion in range is measured parallel to the line of fire, and in deflection at right angles to the line of fire in a horizontal plane.

Dispersion in *range* is positive when the shot falls beyond the MPI. Dispersion in *deflection* is positive when the shot falls to the right of the MPI.

The algebraic sum of the dispersions in range (or deflection) of the several shots of a salvo must equal zero. (See definition of MPI.)

Apparent mean dispersion. The apparent mean dispersion of a salvo in range (or deflection) is the arithmetical average of the disperson in range (or deflection) of the several shots of the salvo, excluding wild shots.

True mean dispersion. The true mean dispersion is the arithmetical mean of the dispersions in range (or deflection) of an infinite number of shots, all assumed to have been fired under conditions as nearly the same as possible and excluding wild shots. (See art. 18A5.)

Hitting space. The hitting space (in range) for a target is the distance behind the target, measured parallel to the line of fire, that a shot striking the top of the target will strike the horizontal plane through the base of the target.

It includes the projection of the target's vertical height upon the plane of the water and the target's horizontal dimension in the line of fire (or depth). It may also include a distance in front of the target within which impacts are likely to produce underwater or ricochet hits on the target.

The hitting space in deflection is the width of the target.

The term, hitting space, as usually used, refers to the hitting space in *range*.

Danger space. The danger space for a material target is the distance in front of the target, measured parallel to the line of fire, that the target could be moved toward the firing point, so that a shot striking the base of the target in its original position would strike the top of the target in its new position.

Straddle. A straddle is obtained from a salvo in range (or deflection) when, excluding wild shots, a portion of the shots of that salvo fall or detonate short and others shots of the salvo beyond the target (right and left, respectively, for deflection).

Error of the MPI. The error of the mean point of impact is the distance of the MPI from the target or other reference point such as the center of the hitting space, measured parallel to the line of fire for range and at right angles to the line of fire for deflection.

18A3. Accidental errors causing dispersion

The problem of spotting is complicated by dispersion. If a battery of guns is fired at the same instant with the same settings in range and deflection, the projectiles will not all land at the same point.

If the battery of guns were stationary and rigidly fixed in elevation and train, variations in range and deflection would be caused by (1) differences in weight and temperature among individual powder charges; (2) differences in projectile weights; (3) variations in angles of projection—the axes of projectiles diverging, in varying amounts, from the continuation of the bore axis as they leave the guns; (4) differences in projectile seating, causing variations in density of loading and initial velocity; (5) differences in erosion among the several guns, with corrections not precisely made; (6) differences in droop among similar guns, and unlike variations in droop with temperature changes; and (7) variations in amount the gun mount will yield and irregularity in action of recoil mechanisms. These are sufficient to justify acceptance of the fact that, even under ideal conditions, *dispersion* in the points of fall of projectiles from several guns, or in several shots from the same gun, may be expected.

If this battery of guns be mounted aboard ship, and each be individually positioned by a pointer and trainer, the rolling and pitching, and the yawing, of the ship itself will further cause dispersion. The motion of the ship may cause the pointers and trainers of the several guns to misalign their sights on the target when the guns are fired. The same effect may result from failure to fire exactly simultaneously, causing different guns to fire at slightly different points in the roll, and thus at different *velocities* of roll. Director-controlled gunfire, although not subject to the same characteristic errors as pointer fire, is subject to its own set of characteristic errors. These are discussed in some detail in articles 18A11 through 18A15.

The errors mentioned above as characteristic of pointer fire, and many of those which are characteristic of director fire, come under the general classification of *accidental errors*. They are revealed by analyses of firings, and their effects are governed by *laws of probability*, as will be explained.

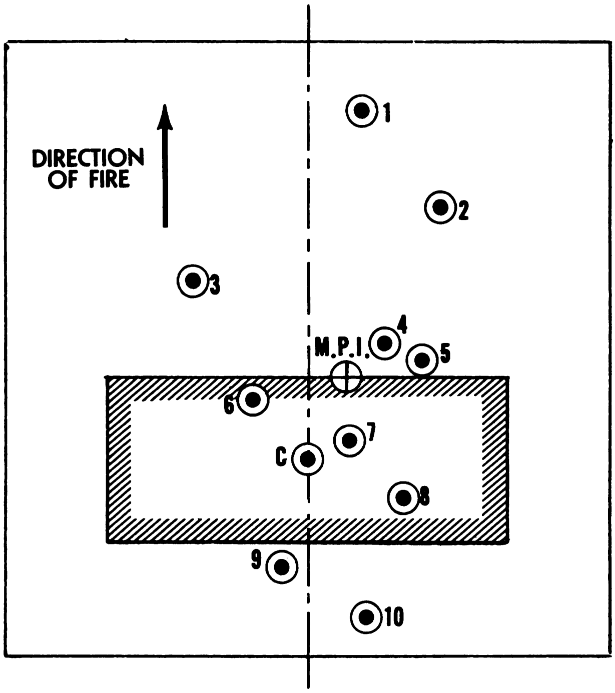


FIGURE 18A1.—Plan view of salvo, showing hitting space.

18A4. Determining the location of the MPI

The definitions in the above paragraph will now be illustrated by an example, representing a salvo from ten 5″/38 caliber guns fired at range 8,500 yards against a target 40 feet high, 600 feet long, and with a beam of 90 feet. The target is situated with its length at 90° to the line of fire.

The danger space in range from column 7 of the range table is 40/20 × 25 = 50 yards. Since the "depth" is 90 feet, or 30 yards, the actual danger space is thus 50 + 30 = 80 yards. As discussed in article 17B11, for most battle ranges the value of hitting space is the same as that for danger space. Hence, in this case, the hitting space can be considered 80 yards. Figure 18A1 represents the plan view of the target shown in terms of hitting space, an area 80 yards in range and 200 yards in deflection. The center of the hitting space is at C. (The fact that the target's deck is not rectangular in shape, causing a narrowing of the hitting space at the extremities, will be ignored.) The points of impact of the several shots are indicated by numbered dots and may be identified by referring to the adjacent table, which gives the location of each impact from the reference axes, in this case taken as intersecting at the center of the target's waterline.

Shot No.	*Distance from Reference Axes*			
	Range		Deflection	
	Over	Short	Right	Left
1	220		30	
2	170		70	
3	130			60
4	100		40	
5	90		60	
6	70			30
7	50		20	
8	20		50	
9		10		10
10		40	30	
Sum	850	50	300	100
—	50		100	
Diff.	800		200	
Mean	80		20	

The location of the MPI is determined by measuring the distance, in range and deflection, of the point of impact of each shot from convenient coordinate axes, and finding the mean of these distances. It is convenient to refer impacts to axes intersecting at the center of the target's waterline, as was done in the table. The mean of these distances is 80 yards over and 20 yards right, which locates the MPI 80 yards beyond and 20 yards right of the center of the waterline.

If we assume that the *error of the* MPI is its distance from the center of the hitting space, this is seen to be 40 yards *over* and 20 yards *right.*

Inspection of figure 18A1, or of the table, shows that the pattern of this salvo is 260 yards in range and 130 yards in deflection. (None of these figures, nor any figures in this chapter, are to be considered as typical.)

18A5. Determining apparent mean dispersion

In determining the apparent mean dispersion it must be borne in mind that it is the arithmetical mean of the dispersions of the several shots, *without regard to sign.* The position of the MPI having been plotted, the several points of impact are *now referred to* the MPI to determine the individual dispersions and the apparent mean dispersion.

Shot No.	*Dispersion*	
	In Range	In Deflection
1	140	10
2	90	50
3	50	80
4	20	20
5	10	40
6	10	50
7	30	0
8	60	30
9	90	30
10	120	10
Sum	620	320
Mean	62	32

The apparent mean dispersion, based on 10 shots, is thus 62 yards in range and 32 yards in deflection. Being based on such a limited number of observations, it is not a true measure of the accuracy of fire. The true measure of the accuracy is the mean dispersion of an infinite number of shots, all fired under the same conditions as those under consideration, and is called the *true mean dispersion.* Although it is obviously impossible to measure the value of the true mean dispersion experimentally, a theoretical value is given by the relation,

$$D = D'\sqrt{\frac{n}{n-1}},$$

in which D is the true mean dispersion, D' the apparent mean dispersion, and n the number of shots from which D' was obtained. The following table gives the values of the ratio of D *to* D', *i. e.,* values of

$\sqrt{\frac{n}{n-1}}$, for salvos of from 2 to 12 shots.

Number of Shots in Salvo	*Ratio of True Mean Dispersion to Apparent Mean Dispersion*
12	1.044
11	1.049
10	1.054
9	1.061
8	1.069
7	1.080
6	1.095
5	1.118
4	1.155
3	1.225
2	1.414

The true mean dispersion, in the above case, is found by multiplying the apparent mean dispersion by 1.054. Hence the true mean dispersion in range, denoted by *Dr,* is 62 × 1.054 = 65 yards, and in deflection, denoted by *Dd,* is 32 × 1.054 = 34 yards.

18A6. Law of probability applied to dispersion

After determination of the true mean dispersion of shots fired by a battery of guns, the next step is the investigation of the manner in which the accidental errors, which resulted in this dispersion, will affect the chances of hitting a target, and how the control of a battery of these guns will be influenced by a knowledge of these errors.

In this study use is made of the *laws of probability,* which deal with the prediction of future occurrences on the basis of information gained from past occurrences. The laws of probability are the basis of the science of statistics, and may apply to almost any event or occurrence.

The law which pertains to symmetrically distributed accidental errors is known as the *normal probability law.* The accidental errors of gunfire follow a fairly symmetrical distribution, and this law is applied to them. It is based upon the following considerations:

1. That positive and negative errors of the same size are equally probable, and hence will occur with equal frequencies.

2. That small errors are more probable than large errors, and hence will occur with greater frequency than large errors.

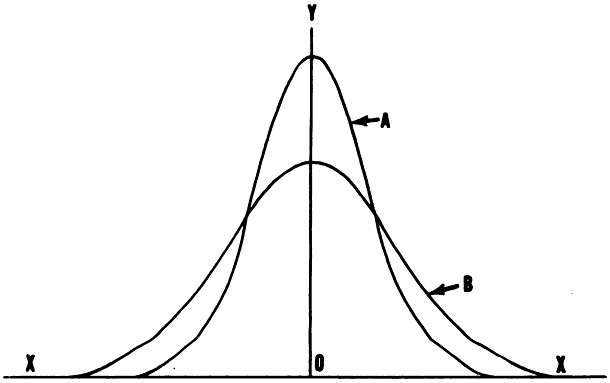


FIGURE 18A2.—Probability curves.

3. That very large errors will not occur (or, more specifically, that very large errors will probably be due to mistakes and not be classifiable as accidental errors).

These considerations all pertain to the probable frequency of occurrence of errors of certain size and sign. Translated into a mathematical equation, the curve representing that equation will have the following characteristics (the abscissas measure the *size of the errors;* the ordinates, the *frequency of their occurrence*):

1. Since positive and negative errors of the same size occur with equal frequency, the curve must be symmetrical to the right and left of the point that denotes zero error ($x = 0$), which is the origin.

2. Since small errors occur more frequently than large errors, the maximum ordinate must occur at the point that denotes the least error ($x = 0$), which is the origin.

3. Since large errors rarely occur, and beyond some limit do not occur at all, the right- and left-hand branches of the curve must each approach the horizontal axis rapidly and meet it at some point.

In figure 18A2 are shown two such curves, as they apply to the accidental errors of gunfire. Curve A is based on a relatively small mean dispersion. (Actually, curve A represents a mean dispersion just two-thirds as great as is represented in curve B, both curves being drawn to the same scale.)

In the determination of dispersion for a gun the student will recall that *wild shots* are excluded. It is, therefore, apparent the that curve will meet the horizontal axis at the limit, on each side of the origin, beyond which shots are excluded as wild shots.

18A7. Determining probability of hitting within a certain error

The true mean dispersion and the probability curve having been determined, it is possible to determine the probability of hitting within a certain distance of the origin, that is, within a certain error, *plus* or *minus*.

A table has been prepared in which this limit, denoted by a, is expressed as a percentage of the true mean dispersion D. The entering argument is a/D, the ratio of the particular error ($\pm a$) under consideration to the true mean dispersion D. The quantity P found from the table is the probability that an error not greater than $\pm a$ will occur, *i. e.*, that the error will lie within the limits $+a$ to $-a$. (The value of D', from which D results, must be obtained from target practices on which the points of impact of all shots in each salvo are measured or photographed.)

It must be understood that this table may be used for the probability of occurrences in general, which follow the normal probability law. In the general case, a represents the error while D represents the index of precision as determined by past observations. (The index of precision refers to the degree of accuracy which has been observed in the past. In the case of gunfire the index of precision is the value of the true mean dispersion.)

From an inspection of the table two facts are readily apparent:

1. For a probability of 0.500, the error will lie between $\pm 0.846D$. Or, the probability of hitting between limits separated by $1.692D$ is 50 percent.

2. The probability of hitting within limits of error equal $\pm 4D$ is 0.999. It follows that a dispersion greater than $4D$ will fall without the curve. In connection with problems in this course the student should consider a dispersion greater than $4D$ as due to a wild shot.

18A8. Probability of hitting when MPI is at center of hitting space

The case pictured in figure 18A1 will now be employed to illustrate the use of the probability table, *in the case where the* MPI *is located at the center of the hitting space.* If the entire salvo be shifted in range and deflection to bring the MPI to coincide with C, it will be seen that shots 4, 5, 6, and 7 are material hits, *i. e.*, hits within the material target. The table will be employed to determine the percentage of an infinite number of shots which may be expected to hit this target.

The probability of hitting in *range*, P_r, is determined by entering the table with a value of $\pm a/D_r$ equal to

Probability of an Error not Greater than ±a in Terms of the Ratio a/D

a/D	P	a/D	P	a/D	P	a/D	P
0.1	0.064	1.1	0.620	2.1	0.906	3.1	0.987
0.2	.127	1.2	.662	2.2	.921	3.2	.990
0.3	.189	1.3	.700	2.3	.934	3.3	.992
0.4	.250	1.4	.735	2.4	.945	3.4	.994
0.5	.310	1.5	.768	2.5	.954	3.5	.995
0.6	.368	1.6	.798	2.6	.962	3.6	.996
0.7	.424	1.7	.825	2.7	.969	3.7	.997
0.8	.477	1.8	.849	2.8	.974	3.8	.998
0.9	.527	1.9	.870	2.9	.979	3.9	.998
1.0	.575	2.0	.889	3.0	.983	4.0	.999

±40/65=0.62. (The hitting space being 80 yards in range, ±40 yards encompasses the hitting space. The true mean dispersion in range, *Dr*, from article 18A5, is 65 yards. The ratio will be carried to two decimal places.) The value of *Pr* is 0.379, to three decimal places.

In deflection the hitting space is 200 yards and the true mean dispersion in deflection, *Dd*, is 34 yards; thus $\pm a = 100$ yards. $\pm a/Dd = 100/34 = 2.94$, and the probability of hitting *in deflection, Pd*, is 0.981.

It is an axiom of the laws of probability that if an event is independently controlled by more than one set of conditions, the probability of its occurrence under all of these sets of conditions is equal to the *product* of the several probabilities of its occurrence under the several sets of conditions. Thus, in a pack of playing cards, the probability of drawing a king is 1/13, and the probability of drawing a spade is ¼. The probability of drawing the king of spades is then the *product* of these two probabilities, or 1/52. In this case, the probability of hitting the target depends upon the probability of hitting in range and the probability of hitting in deflection. Therefore, the probability of hitting, *P*, is the *product* of these two probabilities, or 0.379×0.981=0.372. Then for a salvo of 10 shots about 4 hits should be obtained. (The fact that more or less than this number may be obtained on any one salvo is of no moment at this time, because these laws are based upon a great number of occurrences and do not directly apply to any one.)

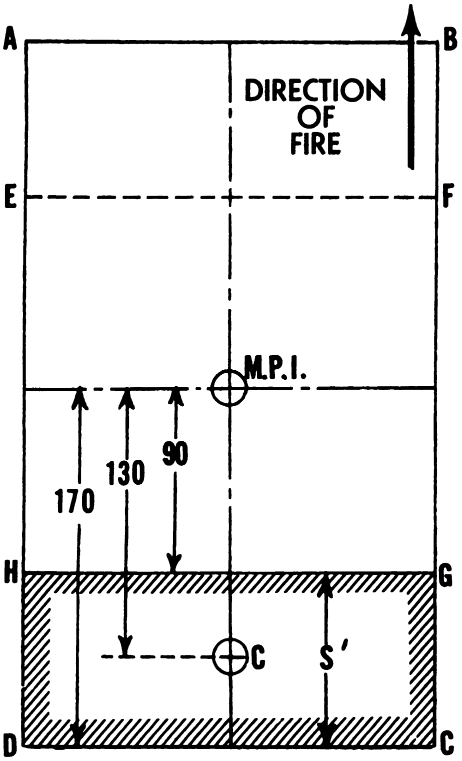


Figure 18A3.—Probability diagram.

Figure 18A1 also shows that the densest portion of the salvo is centered upon and relatively close to the MPI. In article 18A7 it was shown that one-half of the shots, or five in this case, should fall within ±0.846*D* of the MPI, or within 0.846×65=55 yards in range and 0.846×34=29 yards in deflection. In figure 18A1 it is seen that 5 shots are within this limit in range; 4 shots are within this limit in deflection, with 2 more just 1 yard outside the limit.

The above paragraph shows the importance of maintaining the MPI at the center of the hitting space. As the MPI moves away from the center, it carries with it the area of greatest density of impacts, and the probability of hitting falls off very rapidly. For comparison, the probability of hitting this same target will be determined for the case where the MPI lies just one-half pattern, or 130 yards, beyond the center of the hitting space.

Referring to figure 18A3, the center of the hitting space, which is represented by the shaded area, is at C. The MPI is 130 yards beyond and in line with C. In order to find the probability of hitting within the hitting space, in range, it is necessary first to determine the probability of hitting the total area ABCD, using $\pm a$ equal to 170 yards, which is seen to be equal to the error of the MPI *plus* one-half the hitting space, *S'*. This probability is denoted by the symbol Pr_1. Next the probability of hitting within the area EFGH is determined using $\pm a$ equal to 90 yards, which is equal to the error of the MPI *minus* one-half the hitting space, *S'*. This probability is denoted by Pr_2. Now, if Pr_2 is subtracted from Pr_1 the result will be the probability of hitting within area ABCD minus EFGH, or within the *two areas* ABFE and HGCD. These two areas are equal, so that the probability of hitting within the single area HGCD is one-half this result, or

$$Pr = \tfrac{1}{2}(Pr_1 - Pr_2).$$

This problem will now be solved as explained above, first for Pr_1, then for Pr_2, and finally for one-half their difference. True mean dispersion in range, *Dr*, as before, equals 65 yards.

For Pr_1, $\pm a/Dr = 170/65 = 2.62$; and $Pr_1 = 0.963$.
For Pr_2, $\pm a/Dr = 90/65 = 1.38$; and $Pr_2 = 0.728$.
Then $Pr = \tfrac{1}{2}(0.963 - 0.728) = 0.118$.

But $P = Pr \times Pd$. The value of Pd will not differ from the value found above, since the error of the MPI in deflection is zero.

Hence $P = 0.118 \times 0.981 = 0.116$.

18A9. Spotting MPI to center of hitting space

The two cases illustrated in figures 18A1 and 18A3 will be analyzed to see what information may be obtained of interest to a spotter on shipboard. In the first case, with the MPI at the center of the hitting space, the laws of probability show that about four hits (*i. e.,* 0.379×10) in range should be obtained in a 10-shot salvo. Therefore, about six shots will miss the target; and since the first consideration of the normal law states that positive and negative errors will occur with equal frequency, it follows that about three $[(10-3.79) \div 2]$ of these misses will be "shorts."

Probably the most common fault of spotters is the feeling that shorts are wasted, since it is so readily apparent that they have not hit the target, and that ensuing salvos must be spotted up until no shorts are seen. Consideration of relative sizes of pattern and hitting space will show, however, that if the MPI is to be anywhere in the hitting space, some shots must be observed short of the material target, even with the symmetrical shot distribution assumed in this discussion.

Again, remembering that the greatest density of impacts is grouped within a relatively short distance of the MPI ($\pm 0.846D$), it is obvious that *if no shorts are seen* the MPI must be well beyond the center of the hitting space and, at any likely range, well outside the hitting space. Thus the greater part of the salvo, and particularly the densest portion of the salvo, is actually being wasted. Also, as the range increases, the hitting space decreases, the probability of hitting decreases, and the number of shorts which should be seen increases. (Of course, the converse is true; the range is finally reducing to a point where the maximum ordinate of the trajectory is less than the vertical height of the target. In this case the danger space equals the range; the range at which this condition occurrs is called the *danger range.*)

In the second case, the error of the MPI in range is one-half the pattern size. (It should be mentioned that this pattern size does not represent the pattern size of an infinite number of shots, since it was based on the points of impact of only ten shots.) The MPI is 90 yards beyond the material target and the densest portion of the salvo, included within the distance $\pm 0.846Dr$, is entirely beyond the target. The probability of hitting in range is reduced from 0.379 (for error of the MPI equal to zero) to 0.118, or by more than two-thirds. These values clearly demonstrate the necessity of spotting the MPI to the center of the hitting space, which in turn requires a considerable number of observed shorts.

An officer detailed to duties which include spotting should know the probability of hitting at various ranges up to the extreme range of his battery against the *various types of target* which might be encountered. This information will tell him the number of shorts which should be expected or striven for under all possible conditions.

18A10. Accidental errors causing shift of MPI

Another phase of the problem of interest to the spotter is a knowledge of the amount which the MPI's of successive salvos may be expected to vary in location. Since the MPI is the center of the points of impact, which are the results of unpredictable accidental errors, it is logical to suppose that no two salvos will be exactly alike. Or, since successive shots from the same gun, fired under the same conditions, may be expected to vary, the MPI's of successive salvos will also vary.

The MPI of 100 shots (although fired as 10 salvos of 10 shots each) is the geometrical center of the points of impact of these 100 shots. The MPI's of the individual salvos will differ from this aggregate MPI by varying amounts which, however, are still in accordance with the normal probability law. The distance each MPI is located from the aggregate MPI is the dispersion (in range and deflection) of that MPI. The arithmetical mean of the dispersions of several MPI's (with respect to the aggregate MPI) is called the *mean dispersion of the* MPI. This value may be obtained by the equation

$$Do = D/\sqrt{n},$$

in which Do is the mean dispersion of the MPI; D is, as before, the true mean dispersion of the gun; and n is the number of shots in the salvo.

In the example given in article 18A5, the true mean dispersion in range is 65 yards; hence the mean dispersion of the MPI is

$$65/\sqrt{10} = 21 \text{ yards.}$$

If the *mean* dispersion of the MPI is 21 yards, the difference between the MPI's of two successive salvos may be expected to exceed this value. The value of this *average shift* of the MPI (D_1) is found by the relation $D_1 = Do\sqrt{2}$. Thus the average shift between successive MPI's is $21 \times \sqrt{2} = 30$ yards.

While the spotter cannot estimate the MPI of a salvo with any such degree of accuracy, he should expect the number of shorts seen on successive salvos to vary as the MPI's of these salvos move about the center of the hitting space. He should therefore not be too quick to spot when only one or two salvos seem to wander off the target during a string that is, in general, satisfactory.

18A11. Control errors

The only accidental errors so far considered have been those which affect individual guns of a battery. These are known as *gun errors* and should be distinguished from another class of error which affects the battery as a whole. These are known as *control errors* and include those made in rangekeeping, transmitting of data to the guns, and, in director fire, director pointing errors. They are not reflected in increased pattern sizes (*i. e.,* increased dispersion among the guns) but in increased dispersion of the MPI's themselves.

Before the first salvo is fired at a target, as many effects likely to cause error of the MPI as practicable are accounted for. If this salvo has an error of MPI, it is the result of control inaccuracies. There are four general control inaccuracies which may cause error of the MPI. These are listed in the order of probable frequency of their occurrence and the magnitude of their effect:

1. Rangekeeper set up with incorrect range, courses, and speeds.
2. Ballistic corrections based on conditions not existing at the time of firing (initial velocity, wind, air density, and others).
3. Battery not properly aligned with director.
4. Indeterminate errors (Class B and personnel errors).

18A12. Incorrect rangekeeper set-up

The present range to the target is valid only to the extent that its measurement is accurate. An error in this basic range measurement is directly registered as an error in MPI.

Measurements of own-ship course and speed usually are reasonably accurate, but any inaccuracies result in an error of MPI.

The determination of the target's course and speed is made directly from the spotter's estimate of target angle and speed, from the radar plot in CIC, or by rate controlling. Correct values of these two variables are most difficult to determine; they are the chief cause of an incorrect rangekeeper set-up, and thus the chief source of MPI error.

18A13. Inaccurate ballistic corrections

The computer determines corrections necessary to compensate for variations from standard conditions. If the determination of these corrections is based on incorrect values of ballistic wind, initial velocity, air density, and others, the total ballistic correction will be in error and will result in a corresponding error in MPI.

18A14. Improper battery alignment

The alignment referred to here is not intended to mean improper alignment between the guns of a battery. Such misalignment results in greater dispersion and larger pattern sizes, but does not materially affect the error of the MPI of a salvo. The improper alignment referred to here means the misalignment which may exist between the controlling director and the battery as a whole. This type of error is generally caused by failure to director-check the battery and all directors. Thus, a battery which is aligned with one director is not necessarily aligned with another which may be in control. Frequent director checks can assist in elimination of this cause of error in MPI.

18A15. Indeterminate errors

One of the two classes of indeterminate errors results from the fact that some of the computations by fire control instruments are only approximations of the true solutions. They are acceptable because they are susceptible of easier mechanization. These approximations result in *Class B errors,* which are small for normal ranges and therefore cause minimum error in MPI. However, at extremely short or long ranges the errors may become large, depending upon the instrument concerned, and thus may seriously affect the MPI. When Class B errors are known to be large, they are not admissible as accidental, and steps must be taken to make correction for them.

The other class of indeterminate errors is assignable to control personnel. An example would be the director pointer or trainer being off the point of aim when the salvo is fired. Only training and experience can prevent the occurrence or reduce the magnitude of such mischance. Small errors of this type merely cause a slight shift or dispersion of MPI and should not be corrected by the spotter. The director operator should inform the spotter of large discrepancies in the point of aim, in order that the spotter may distinguish this error from others.

18A16. Summation of errors

During actual firing a spotter cannot analyze each fall of shot to determine the exact geometrical MPI of a salvo. Splashes last only a matter of seconds, and the firing situation is probably changing even during that short interval. The spotter must have previously analyzed all probable errors and the reasons for them. This knowledge, coupled with practical training, will enable him to make instant and intelligent decisions as to the proper correction or spot necessary to hit the target.

To summarize, the general errors attending shipboard gunfire are:

1. Accidental gun errors causing dispersion of shots. These errors are only compensated to the extent of achieving desired pattern sizes. Most of the errors are eliminated by careful design, frequent checks of battery alignment, normal upkeep of the battery, and the training of gun crews.
2. Accidental gun errors causing a shift in the MPI of successive salvos. The shift in range is usually small; a noticeable shift in deflection is observed when using radar aim.
3. Control inaccuracies causing error of MPI. It is the primary duty of the spotter to "spot" the corrections in range and deflection necessary to bring the MPI of a salvo to the desired point of impact. He should recognize the first two classes of errors in order to spot the error of MPI caused by control inaccuracies.

B. The Spotter

18B1. General function of the spotter

The primary function of the spotter is the correction of range and deflection errors of the MPI so as to bring the shots on the target, or, in other words, to establish the hitting gun range and deflection. The basis of these corrections is his own observation combined with those of the fire control radar operator. As a rule, in good visibility the spotter will estimate the necessary deflection correction, and range corrections will be obtained from the radar. Under unfavorable conditions both range and deflection corrections will be obtained from the radar. Prompt and accurate correction of initial errors may be the deciding factor in a naval engagement.

In the event of radar failure, optical spotting must be relied upon for all corrections necessary to establish the hitting gun range and deflection. Therefore in the initial discussion of the spotter's problems, it will be assumed that radar is not available.

18B2. Other functions and duties

The spotter's detailed duties and spotting procedures are prescribed in the ship's *battle bill* and fleet doctrinal publications. Included are the following important duties:

1. Search for and locate the enemy.
2. Describe the enemy forces (number of ships, bearing, *etc.*).
3. Estimate all values for the initial rangekeeper set-up (enemy speed, target angle, and range).
4. Notify Plot and Control of any changes of target angle, target speed, and enemy deployment.
5. Keep Conn and Control informed of the tactical situation.

18B3. Visual estimation of target course and speed

The spotter who can estimate target angle (used in the determination of target course) and target speed with fair accuracy will greatly assist the rangekeeper operator in arriving at an early solution of the problem, and also aid him in checking the rangekeeper set-up. On the other hand, if the spotter's estimates are inaccurate the rangekeeper operator will have to make many changes to arrive at a correct solution.

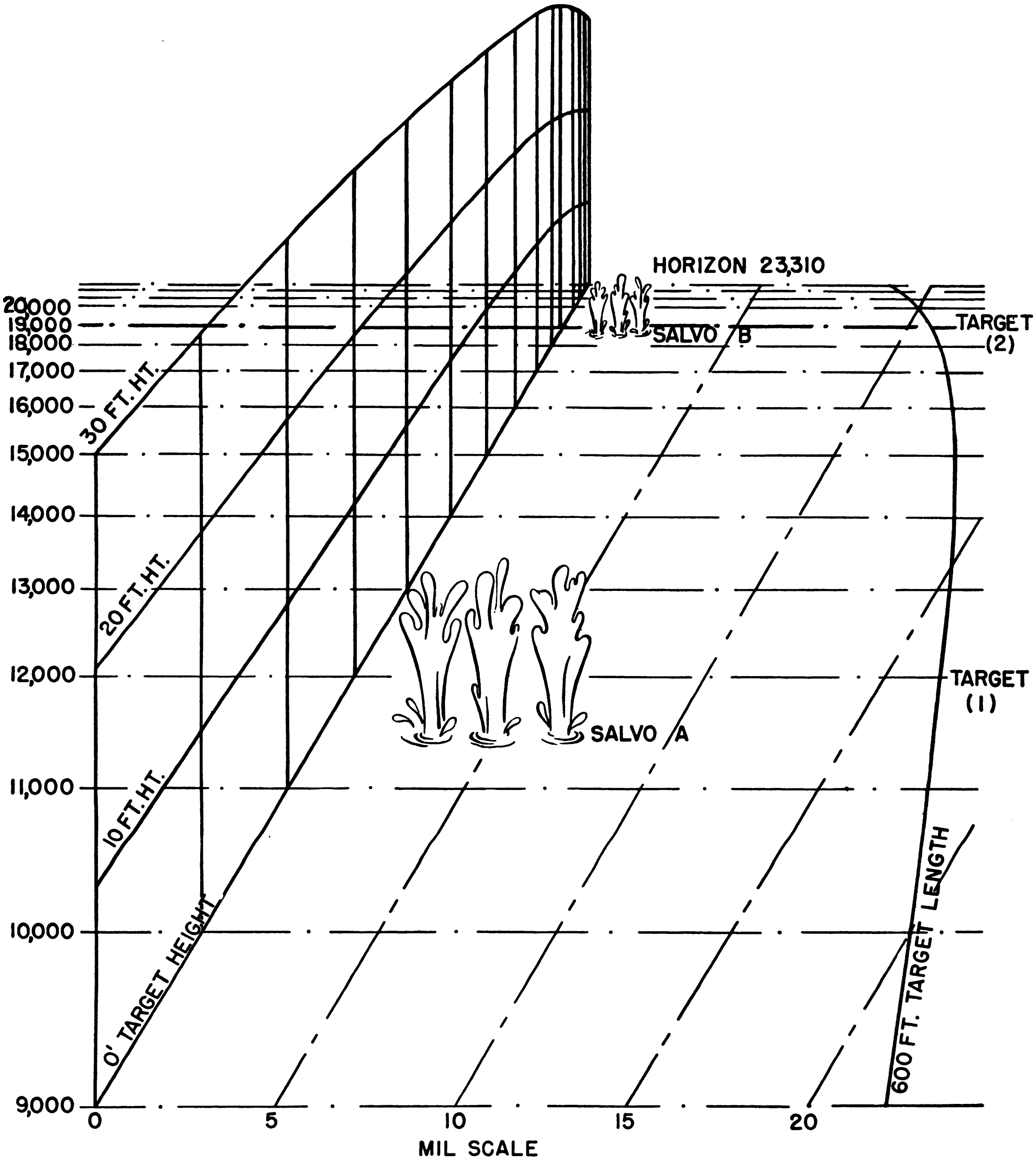
To estimate target angle the spotter must know the structural details of all likely targets. Silhouettes and scale models of all probable targets are furnished each ship. The spotter should study the details of these visual aids, not only for the purpose of recognizing the enemy, but also for estimating target angle. In estimating target angle, the spotter should make use of prominent objects such as bridges, breaks in the deck, stacks, masts, and other features. By observing the opening and closing of the apparent distance between such details, the spotter can estimate the angle the enemy ship makes with the line of sight.

Target speed can at best be only roughly estimated. Here again, knowledge of enemy ships is valuable, particularly in the case of maximum speeds. If in line of battle, target speed may be estimated as about 1 or 2 knots less than the maximum speed of the slowest ship in the formation, considering any damage reports which may have been received.

The best speed estimates can be made only by men who have had extensive training and experience. The aids used by a spotter in a direct estimation of target speed are smoke from the stacks, bow wave, and stern wake.

18B4. Visually spotting error of MPI in deflection

Correcting the deflection is extremely important not only for hitting but also because, in long-range surface fire, it is difficult to spot in range if the deflection error is excessive. A salvo which is widely off a single target should first be spotted in deflection, and the succeeding salvo spotted in range. In estimating deflection spots, the estimated target width in mils should be used as a guide. Also, telescopes, binoculars, or other optical devices fitted with mil scales furnish a suitable means of estimating deflection errors.



NOTE: DIAGRAM FOR SPOTTING HEIGHT OF 100 FT.

RANGES BEYOND HORIZON

HT.(FT)	RANGE (YARDS)	HT.(FT.)	RANGE (YARDS)	HT.(FT.)	RANGE (YARDS)
10	30,700	50	39,700	90	45,400
20	33,600	60	41,300	100	46,600
30	36,100	70	42,800	110	47,600
40	37,900	80	44,200	120	48,900

FIGURE 18B1.—A typical spotting diagram.

With a high-speed target, the spotter should bear in mind that the apparent MPI in deflection should be held abaft the point of aim in order to allow for the travel of the target while the splashes are forming. In other words, it must not be assumed that full splashes form instantaneously at the impact of a salvo. The time lag is only a few seconds at most, varying with the caliber of projectiles, but is sufficient to allow considerable movement of a high-speed target.

18B5. Visually spotting error of MPI in range

One of the most common mistakes made by the untrained spotter is to underestimate the amount of the range error at long ranges. This is due to the fact that a given range error will subtend a much smaller angle at long ranges than it does at short ranges. However, with good visibility ond a spotting height of 120 feet or more, the error of MPI can usually be estimated with reasonable accuracy at ranges up to 15,000 yards. This is accomplished by observing the position of the bases or slicks of the splashes relative to that of the waterline of the target.

Experience in determining range error can be gained during target practice and by individual practice on a spotting board, which simulates the appearance of splashes relative to the target as viewed from a spotter's station. *Spotting diagrams* are used in conjunction with such training to indicate the relative displacement of a salvo from the target and to estimate ranges. Figure 18B1 shows a typical example for a spotting height of 100 feet and target heights of 10 feet, 20 feet, and 30 feet. Such a diagram is constructed by means of dip curves for the particular height of a spotting station. Range lines are drawn at intervals of 500 or 1,000 yards, from minimum range to that of the horizon. These range lines represent angular distance below the horizon at which any object would appear from a height of 100 feet, if observed on the range lines so marked. The distances between the range lines represent the apparent range differences as viewed by an observer at the spotting height for which the diagram was constructed. The method of construction and the dip curves are available in Fleet training publications and are not described here.

A study of figure 18B1 makes it evident that salvo A is short of the imaginary extension of the waterline of a target at 12,000 yards by about 500 yards. However, the error of a salvo fired at a target at 19,000 yards is not so apparent. The 500-yard error of such a salvo (indicated on the diagram as salvo B), appears as little or no error in apparent distance from the extended waterline of the target. Thus it can be seen that for shipboard spotting at such a range, the splashes must be in line with some portion of the target before the spotter can reasonably tell whether the salvo is over or short, to say nothing of estimating the amount of the error. In addition to its use for estimating range and range errors, the spotting diagram shows the number of mils a given target length will subtend at any given range. For example in figure 18B1 a 600-foot target will subtend 20 mils at 10,000 yards range.

C. Methods of Spotting

18C1. Spotting terminology

It is important that the proper terminology and order of spots be observed by the shipboard spotter.

The surface problem. For surface fire, only range and deflection are spotted. The correction necessary to bring the MPI on the target is given in the following terminology and order.

1. Deflection correction—RIGHT or LEFT, in *mils.*
1. Range correction—ADD or DROP, in *yards.*

Where no correction is necessary, the designation NO CHANGE is used. Typical examples of spot transmissions by telephone are RIGHT 10, ADD 1,000 or DROP 500.

The AA problem. For air targets, corrections to bring the burst on the target are needed in three dimensions. Even well-trained personnel find it almost impossible to estimate errors rapidly in three dimensions. AA spotting is therefore generally ineffective and is usually not attempted except in cases of obvious constant system errors.

The proper terminology for spotting in the AA problem is as follows:

1. Deflection correction—RIGHT or LEFT, in *mils.*
2. Height-of-burst correction—UP or DOWN, in *mils.*
3. Range correction—ADD or DROP, in *yards.*

Deflection and elevation spots will normally be made by the control officer. Range spots will be made by the rangefinder or radar operator, and all spots will normally be transmitted electrically.

Naval gunfire support. In shore bombardment, as in AA fire, spots in three dimensions may be necessary. The terms are the same as in the preceding paragraph, but the units are not the same. When naval guns are used to support landing operations, joint forces are involved. The Navy, Army, and Air Force have a standardized spotting terminology for joint operations which will differ from the above, in that all corrections are spotted in yards. At the rangekeeper or computer, deflection and elevation spots must be converted to angular units before being applied to the computer.

18C2. Methods of spotting

It is evident from the preceding discussion that certain methods of spotting and certain other techniques to assist in the control of gunfire must be employed by the shipboard spotter in the difficult problem of estimating the MPI error in range.

It must be borne in mind that these methods and techniques are but general guides and are in no way intended to replace or abrogate actual procedures which are laid down in detail in Fleet and Force doctrines. Such doctrines must be perfectly known and rigidly followed by the spotter under all conditions. This demand may seem restrictive, but it is necessary that only proved and sound principles be employed. Individual untried ideas, which are likely to produce negative results, are excluded by the ruling.

Subject to the foregoing qualifications there are two methods of spotting:

1. The direct method.
2. The bracket-and-halving method.

There are also three other techniques used in the control of gunfire which are closely related to spotting and must be discussed at this point, namely:

1. Ladders.
2. Barrages.
3. Tracer control.

The use of any of the above methods or techniques is determined, among other things, by the type of battery firing, the type of target, the range, and the visibility.

18C3. Direct methods

Spotting by the direct method is, as its name implies, the spotting of salvos (splashes) direct to the target. This is the most desirable procedure, but its use is very limited. For reasonably accurate spotting at a range of 15,000 yards, a spotting height of 120 feet is required. It is also necessary that the splash be relatively close to the target, and that the rangekeeper set-up be fairly accurate. These considerations limit this method to main-battery fire at relatively short ranges.

A thoughtful analysis of the problem with reference to the spotting diagram in figure 18B1 reveals that the greatest limitation of the direct method is the matter of range. Deflection spots can be made with equal accuracy at any visible distance. If, then, air spots are available, and the plane spots in range with the ship spotting in deflection, the direct method can be used by the main battery at any range at which a portion of the splash is visible to the shipboard spotter. Air spotters cannot spot accurately in deflection unless they have a line of sight containing the firing ship and the target. Radar spotting is usually direct, even at considerable ranges.

18C4. Bracket-and-halving method

The bracket-and-halving method is used at long ranges by the main battery when no air or radar spot is available. At great distances it will be impossible to tell if a splash is short of or over a target, unless the two are in line. If the splash and target are not in line, or if the splash does not line up with a ship in the formation whose range is approximately that of the target, the first spot is made in deflection only. When target and splashes are in line in deflection, a range spot is made in such a direction and amount as to "cross" the target *definitely.* The direction of the next spot is reversed, and the size of the spot is cut in half. This "halving" is continued until a straddle is obtained, at which time it may be appropriate to shift to rapid salvo or to continuous fire. The spot should not be reduced below pattern size. Once a straddle is obtained, *centering* deflection spots only should be made, as long as the spotter is sure he has both short and over splashes. If, however, over splashes are obscured by the target or by shorts, every third or fourth salvo should be fired with an add spot of one pattern size, so as to lift the entire salvo over the target. Only thus can the spotter know his straddles were not all shorts in reality.

18C5. Ladders

When ranging is difficult and visibility poor because of fog, smoke, or darkness, the use of *ladders* is of considerable assistance to a spotter. Ladders are not particularly adaptable to fast-moving targets. There are many variations of this technique. However, it is only necessary to understand its fundamental principles. Fire is deliberately opened short, and succeeding salvos are fired so as to approach the target in steps not less than pattern size. As soon as the target is crossed, the steps are reversed and halved until the target has again been crossed. After a straddle has been attained, a *rocking ladder* may be used in conjunction with slow timed fire or with rapid salvo or continuous fire. This consists of moving the pattern back and forth across the target by small arbitrary successive spots such as +100, 0, −100, . . . introduced at the computer or rangekeeper. It has the effect of increasing the pattern size, which may be valuable when firing against a target capable of rapid maneuvering. When this method is used, care must be taken to make correcting spots only when the zero salvos of the ladder series fall. The rocking ladder can be used in conjunction with air or radar spotting, so long as the spotter is kept informed that this technique is being used.

18C6. Barrages

The barrage method of control consists of placing a zone of fire short or over the target, according to whether the target is closing or opening range. The gun range is kept constant until the target passes through the zone, and is then lowered or raised as necessary to force a second passage through the barrage, continuing the movement of the barrage as may be necessary. This system is used by smaller-caliber, fast-firing batteries against light, fast-moving targets. It is the spotter's function to determine when the barrage should be shifted, and in which direction and how much it should be moved.

18C7. Tracers

The tracer method of control consists of spotting shots by noting the error as the tracer passes the target. It is used chiefly in spotting machine-gun fire. This method may also be used in addition to others in spotting larger-caliber projectiles (*i. e.*, 5″/38 cal. or larger), particularly at short ranges. At longer ranges, tracers are of doubtful assistance to the spotter, because of the difficulty in keeping them in sight or in judging when they pass the target. Under certain light conditions the tracers cannot be seen clearly, and should not be relied upon except for short-range firing.

18C8. Short-range spotting

Spotting the fall of shot at very short ranges differs from other spotting problems in that range errors are not difficult to judge. However, in determining deflection errors at short ranges, consideration must be given to the travel of the target and the spotter's position relative to the line of projectile flight. For example, with the firing ship and target on opposite courses, target to starboard, a shot fired with correct deflection but long in range will appear to the spotter to be in error to the left of the target. Special short-range splash diagrams are constructed as an aid to the spotter in this type of firing; instructions for their preparation and use are available in publications carried by all ships.

18C9. Radar spotting

Radar, using Type B presentation, gives accurate range errors under any visibility conditions. Therefore, it has completely replaced visual spotting as the primary means of determining range errors. However, bearing discrimination by radar has not yet become sufficiently accurate to justify its use as the primary means of deflection spotting under conditions of good visibility. Normally in a day action under favorable visibility conditions the following procedure is followed in spotting:

1. When splashes can be unmistakably identified on the radar screen, direct radar spotting in range is employed.
2. When splashes can be seen visually, the top spotter on the ship employs direct spotting in deflection.
3. Any available aircraft spots are used as a check.

In the event of a night action, or action under conditions of reduced visibility, radar will normally be employed for both range and deflection spots. The technique of radar spotting as it applies to a specific radar and method of presentation is described and illustrated in section G of chapter 20.

18C10. Pyramiding spots

Spot pyramiding is the application of a new spot before the effect of a previous spot has had time to become apparent. It can occur only at rapid fire, when the interval between shots or salvos is less than the time of flight plus the spotting interval. In that case, when a salvo lands there are one or more other salvos in the air. Suppose the spotter makes a spot on the salvo which has just landed. This spot is applied and a new salvo is fired with the corrected ballistic thus arrived at. Then one or more of the salvos which were already in the air lands, and the spotter, forgetting that his previous spot has not had time to show its effect on the fall of shot, spots again. This spot is applied to the next salvo fired, with the result that this salvo is over-corrected and will probably miss, as will subsequent salvos until the spotter sees his mistake and spots back again to remove the pyramided spot.

In order to help the spotter avoid pyramiding, the time-of-flight signal mechanism is used. This mechanism may be incorporated in the rangekeeper or may be in the form of a separate time-of-flight clock. It is operated by the rangekeeper operator or an assistant, who presses a button when the salvo on which a spot is applied, is fired. Just before the salvo lands, the mechanism sounds a buzzer which informs the spotter that a spotted salvo is about to land. When this system is used, the spotter, after making a spot, waits for the buzzer before making another spot.

Spot pyramiding is a very common fault and has a disastrous effect on accurate control of fire. Every means available must be used to prevent it, and these means must be carefully and correctly operated. If they are improperly operated, they may cause worse errors than they are designed to prevent. For example, if the time-of-flight mechanism operator forgets to press the button for a spotted salvo, and the spotter waits for it, he may continue to wait after it becomes apparent that his previous spot was incorrect. In such a case the operator making the mistake should advise the spotter of the situation as soon as he himself realizes it. Some ships have a *Spot Coordinator,* located in the plotting room, who is responsible for the prevention of pyramiding as well as for the coordination of radar, shipboard visual, and air spots.

When modern fire control systems are being used to solve the fire control problem, the process described in subsequent chapters as *rate control* is used to make constant corrections to the solution. If spots are applied at the same time as rate control corrections, the effect is the same as pyramiding of spots. This provides an additional reason for not ordinarily attempting to spot bursts in antiaircraft fire.

Chapter 19

SURFACE FIRE CONTROL PROBLEM

A. General

19A1. Introduction

The fire control problem requires for its solution the collection of essential data, computations based on these data, and arbitrary correction of the results.

In general, the Navy now uses mechanical or electrical units organized into fire control systems to perform as much of the detailed work as possible. This procedure permits greater accuracy, much shorter time for solution, better protection of personnel, and greater flexibility than is possible with any non-mechanized method of control.

19A2. Fire control systems

There are three broad classes of gun fire control systems:

1. *Surface systems,* utilizing estimated values of target course and speed and measured values of range, relative bearing, and own-ship speed and course; computing necessary corrections including deck-tilt and trunnion-tilt compensation; resolving ship and target motion into linear rates; predicting the future position of the target on the basis of these rates; and computing and transmitting gun orders.
2. *Dual-purpose systems,* which are similar to the surface systems except that, since they fire at air as well as surface targets, they measure, in addition, target elevation as an original input.
3. *Relative-rate systems,* in which relative motion of own ship and target is measured by tracking the target and by using the torque generated in tracking to precess a system of gyroscopes, and modifying the gyro output by such corrections as may be necessary to obtain correct gun orders.

In practice, the solution of the problem by a specific fire control system is specialized within certain limits dictated by the primary use of that system. A single-purpose surface battery system which is designed primarily for surface fire can operate on the assumption that all targets are on the surface, and it can disregard the effects of a small angle of elevation or depression of the line of sight. With this system it is perfectly possible to fire at elevated targets in shore bombardment, or even at aircraft within the elevation limits of the guns, but such action requires arbitrary corrections or interconnection with the dual-purpose computer. Since heavy machine guns are designed primarily for shooting at incoming air targets, there is no concern about the point of fall in the conventional sense, and the machine-gun fire control system can function well without some of the units which are absolutely essential to the surface or dual-purpose system. The dual-purpose fire control system limits the accuracy of its fire against surface targets, in order to be effective against aircraft and still stay within necessary limitations of space and weight.

The next few chapters are concerned with a functional explanation of the solution of the fire control problem. The surface-problem solution being simpler than that for an air target, the present chapter explores the basic nature of the surface problem and the principles required for its analytical solution. It also introduces the student to a typical array of fire control mechanisms which have been developed to perform certain of the necessary computations. In succeeding chapters, a fairly detailed investigation is made of the design and function of representative types of the three classes of fire control systems mentioned above. Definitions of terms and symbols are to be found in appendices E and F.

B. Analytical Solution *

19B1. Steps in solving the fire control problem

The solution of the problem is to be considered in five steps:

1. Establishing present target position.
2. Computing necessary offsets from the line of sight.
3. Correcting for the effects of deck inclination.
4. Computing gun orders.
5. Correcting the fall of shot.

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*See also ch. 17.

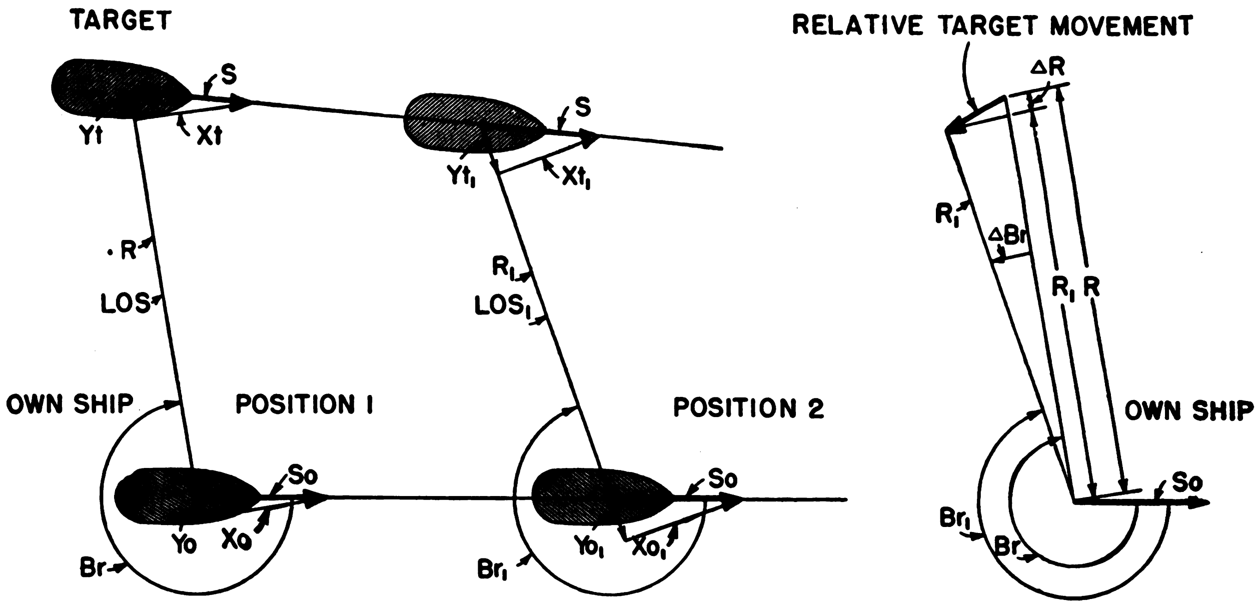

FIGURE 19B1.—Relative target motion.

19B2. Establishing present target position

The first step in the solution of the problem is to establish the line of sight to the target by radar or optical instruments. Accurate measurements are essential for the following:

1. *Present range* (*R*). The observed distance from ship to target, measured along the line of sight. This quantity is determined by rangefinder, by fire control radar, or if no better method is available, by estimate.

2. *Relative target bearing* (*Br*). The angle between the vertical plane through the fore-and-aft axis of own ship and the vertical plane through the line of sight, measured in a horizontal plane clockwise from the bow. Most of the computing devices used in the Navy for solution of the surface problem assume that own ship and target are in the same horizontal plane. Most gun directors used with these computers, because of structural considerations, are trained in a plane parallel to the ship's deck, so of necessity measure target bearing in this plane. Target bearing measured in the plane of the deck (*B'r'*, called director train) is converted to the horizontal plane by a computed correction, *jBr,* called *deck-tilt correction,* to become *Br.* *B'r'* is measured with director sights or fire control radar.

If ship and target were stationary, the only corrections necessary would be those for wind and for the ballistics of the gun. However, the practical difficulty of the solution is increased by the need for computing and applying corrections for relative motion of own ship and target, and for deck inclination with respect to the horizontal.

19B3. Relative target motion

When ship and target are moving with respect to each other, gunfire, to be accurate, must compensate for the error caused by their relative motion during the time of flight of the projectile.

An appreciable time interval elapses while the projectile is in the air. This time is significant when it is considered that a ship at 30 knots is actually traveling 16.89 yards per second.

The method employed analyzes the relative motion of own ship and target to determine the rates at which range and bearing are changing, computes the amount of change during any desired time interval, and applies this change to the original measured quantity to produce continuously accurate values of the coordinates of present target position. The same rates, multiplied by the time of flight, compute the ***predicted*** change in target position during the time of flight. This procedure may be compared to the working of a clock, which, once set correctly and being so constructed that it measures the rate of the passage of time, can add increments of time to the original setting and supply us with the correct time at any later instant.

Figure 19B1 illustrates the nature of the change in range and relative target bearing with a surface target. At position 1, the relative target bearing is *Br,* the present range *R.* During time interval ΔT, the ships move to position 2, where the new present range is R_1 and the relative target bearing Br_1. Each ship has moved a considerable distance, but the change in relative positions has been comparatively small. The range has decreased by ΔR; the bearing has been changed by ΔBr. Over a period of time, these small changes accumulate and may result in a large change in relative position.

19B4. Components of relative target motion

The apparent motion of the target as seen from the deck of own ship is the resultant of the motion of both vessels. To take a simple case, if both ships are steaming down the line of sight toward each other, each at the rate of 30 knots, it is apparent that the range is closing at the rate of 60 knots. Since this is true, the component of relative target motion affecting range can be obtained by combining the range component of own-ship motion with the range component of target motion. The deflection component can be similarly handled.

In the chapter on exterior ballistics, the line-of-sight diagram was presented, with own-ship and target motion represented by vectors. The length of the vector represents speed, while the direction of the vector indicates course. The vectors were resolved into their components in and across the LOS. These components are:

Symbol	*Definition*
Yo	Range component of own-ship velocity. The horizontal component of own-ship velocity along the line of sight.
Yt	Range component of target velocity. The horizontal component of target velocity along the LOS.
Xo	Lateral component of own-ship velocity. The horizontal component of own-ship velocity across the LOS.
Xt	Lateral component of target velocity. The horizontal component of target velocity across the LOS.

These components can be combined to provide range and bearing rates:

Symbol	*Definition*
dR	Range rate. The time rate of change of range. The component of relative target motion along the LOS. $dR = Yo + Yt$.
RdBs	Linear bearing rate measured at the target. The component of relative target motion across the LOS. $RdBs = Xo + Xt$.
dBs	Angular bearing rate. The time rate of change of target bearing. $dBs = \frac{K \times RdBs}{R}$.
K	Constant.

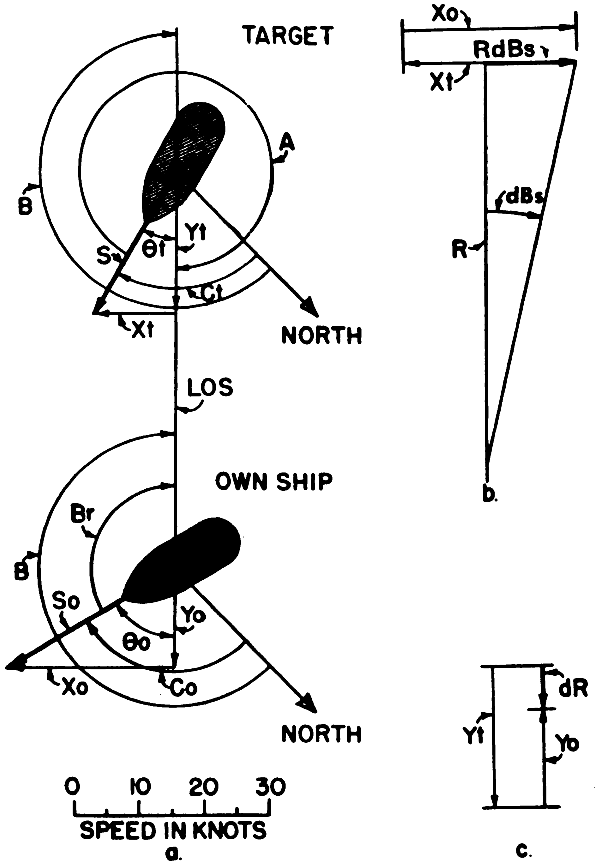

FIGURE 19B2.—Line-of-sight diagram.

These components are illustrated in figure 19B2. The line-of-sight diagram is used to derive the components of own-ship and target motion. It is evident that:

$$Xo = So \sin \theta o = So \sin Br.$$
$$Xt = S \sin \theta t = S \sin A.$$
$$Yo = So \cos \theta o = So \cos Br.$$
$$Yt = S \cos \theta t = S \cos A.$$

The direction of the effect of the components on range or bearing can best be ascertained by observation. Consider the target stationary; then examine the direction of *Yo* and *Xo*. If, as in figure 19B2, *Yo* causes range to increase, it is considered positive. *Xo*, the bearing component, is positive if, as in the figure, it causes the line of sight to move to the right (or the numerical value of bearing to increase). Then consider own ship to be motionless, and assign algebraic signs to target components by the same reasoning. In figure 19B2, by inspection, Yo and Xo are positive and Yt and Xt negative.

19B5. Range rate

In figure 19B2 (C) the range components have been added algebraically to form the range rate. Since Yt is greater than Yo and is negative, dR is negative, decreasing the range.

Range rate must be converted from knots into yards per second, since range is measured in yards. The conversion constant is the result of the following equation:

$$1 \text{ knot} = \frac{2{,}027 \text{ yards per hour}}{3{,}600 \text{ seconds per hour}}$$
$$= 0.563 \text{ yards per second.}$$

19B6. Bearing rate

In figure 19B2 (B) the bearing components are added to obtain the linear bearing rate $RdBs$. Since Xo is positive and larger, $RdBs$ is positive (increasing).

Since bearing is an angle, rate of change of bearing must be converted to an angular rate. $RdBs$ is linear. The conversion is accomplished as follows:

$$1 \text{ knot} = 0.563 \text{ yards per second.}$$

$$1 \text{ yard per second} = \cfrac{1}{\cfrac{R \text{ (yds)}}{1000}}$$

$$= \frac{1000}{R \text{ (yds)}} \text{ mils per second.}$$

$$1 \text{ mil} = 3.438 \text{ minutes of arc.}$$

$$1 \text{ knot at range } R \text{ (yds)} = 0.563 \times \frac{1000}{R \text{ (yds)}} \times 3.438$$

$$= \frac{1936}{R \text{ (yds)}} \text{ minutes of arc per second}$$

Therefore, dBs (min. of arc per sec.)

$$= \frac{1936 \times RdBs \text{ (kts)}}{R \text{ (yds)}}$$

19B7. Use of range and bearing rate

Range and bearing may be "kept" or computed continuously by applying the rates derived in the preceding paragraphs. Additional definitions which are necessary include:

Symbol	*Definition*
ΔR	Increment of range. The change of range during a definite time interval. $\Delta R = dR \times \Delta T$.
ΔBr	Increment of bearing. The change of bearing during a definite time interval. $\Delta Br = dBs \times \Delta T$.
jR	Initial range.
jBr	Initial relative bearing.
Tf	Time of flight.
cR	Generated present range. $R = jR + \Delta cR$.
cBr	Generated relative bearing. $Br = jBr + \Delta cBr$.
$R2$	Advance range (predicted range). $R2 = cR + (dR \times Tf)$.
$Br2$	Advance relative bearing (predicted relative bearing). $Br2 = cBr + (dBs \times Tf)$.

By continuously applying the rates it is possible to keep accurate values of present range and bearing, even though measurements of range and bearing may be interrupted. And by using time of flight, it is possible to predict the position of the target at the end of the time of flight, assuming that relative motion is constant for the short time interval involved. In practice, the error resulting from the fact that $RdBs$ is a linear instead of an angular rate is reduced in modern computing instruments by using very short time intervals in the computation. Also for obtaining each successive instantaneous value of R and Br the new values of dR and $RdBs$ obtained for the preceding instant are used.

This completes the analytical solution of the problem of maintaining continuous values of present and

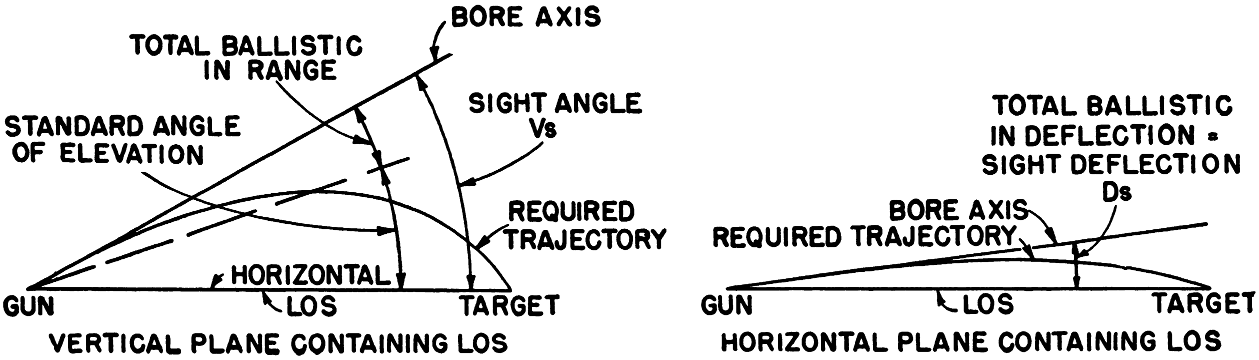
BORE AXIS
TOTAL BALLISTIC IN RANGE
STANDARD ANGLE OF ELEVATION
SIGHT ANGLE Vs
REQUIRED TRAJECTORY
HORIZONTAL
GUN
LOS
TARGET
VERTICAL PLANE CONTAINING LOS
TOTAL BALLISTIC IN DEFLECTION = SIGHT DEFLECTION Ds
BORE AXIS
REQUIRED TRAJECTORY
GUN
LOS
TARGET
HORIZONTAL PLANE CONTAINING LOS

FIGURE 19B3.—Application of Vs and Ds.

predicted range and bearing. It is immediately apparent that because of the time required for computation, the large number of calculations necessary, and the errors introduced by using finite time intervals, the analytical solution is of no practical value in modern gunnery. Mechanical and electrical rangekeepers and computers have been perfected which accomplish all the steps of the computation automatically on the basis of accurate basic inputs.

19B8. Computing bore offsets

The angles by which the gun bore must be offset from the line of sight in order to hit the target are sight angle (*Vs*) in elevation and sight deflection (*Ds*) in train.

19B9. Sight angle

The chapter on exterior ballistics presented the method of determining the vertical angle by which the bore axis of the gun must be offset from the line of sight. This angle is made up of the standard angle of elevation (column 2 of the range table), plus the angular equivalent of the total ballistic correction in range, plus the angular equivalent of range spots. In fire control, this angle is called sight angle (*Vs*). It should be noted that one of the largest components of the range ballistic correction is normally the correction in range for relative motion of own ship and target.

19B10. Sight deflection

The horizontal angle by which the bore axis must be offset from the LOS is the angular equivalent of the total ballistic in deflection, plus any deflection spots. The details of this computation were also covered in the chapter on exterior ballistics. Again, a large part of sight deflection is normally the correction for relative motion of own ship and target.

19B11. Counteracting the effects of deck inclination

Inclination of the deck with respect to the horizontal can be considered to be made up of two components, one in the plane through the line of sight, the other in a plane perpendicular to this plane through the line of sight. The first is relatively easy to counteract, since it affects only gun elevation. By keeping the line of sight on the target as the deck moves, the gun axis is maintained in its proper position. The deck inclination across the line of sight is more difficult to counteract.

19B12. Trunnion tilt

Inclination of the deck across the line of sight tilts the gun trunnions out of the horizontal. For the purpose of simple explanation, the entire gun mount is considered to rotate around the line of sight. Figure 19B4 illustrates the effect of this motion. As one looks along the LOS, the gun trunnions are seen to be tilted to the right, swinging the elevated gun barrel to the right. It is apparent that this will cause a deflection error to the right, if not corrected. The same movement decreases the amount the gun bore is elevated above the horizontal, introducing a range error.

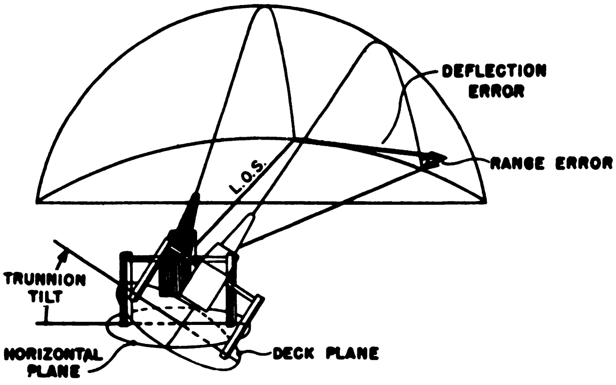

FIGURE 19B4.—Effect of trunnion tilt.

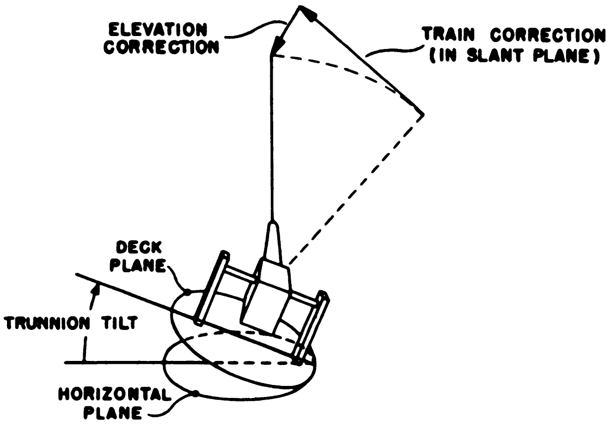

FIGURE 19B5.—Corrections for trunnion tilt.

What actually has happened is that the sight angle and sight deflection computed for the vertical and horizontal planes respectively are now being applied in two entirely different planes; *i. e.*, in planes perpendicular to and parallel to the deck plane, which is now inclined. To take the extreme case, a trunnion tilt of 90° would result in the bore axis being offset horizontally by the amount of *Vs* and vertically by the amount of *Ds*.

The deflection error resulting from trunnion tilt is normally large and in the direction of the tilt. The range error is small and almost always causes a decrease in gun range. An examination of figure 19B4 shows also that the angular displacement of the gun barrel depends upon the amount of gun elevation and the amount of trunnion tilt.

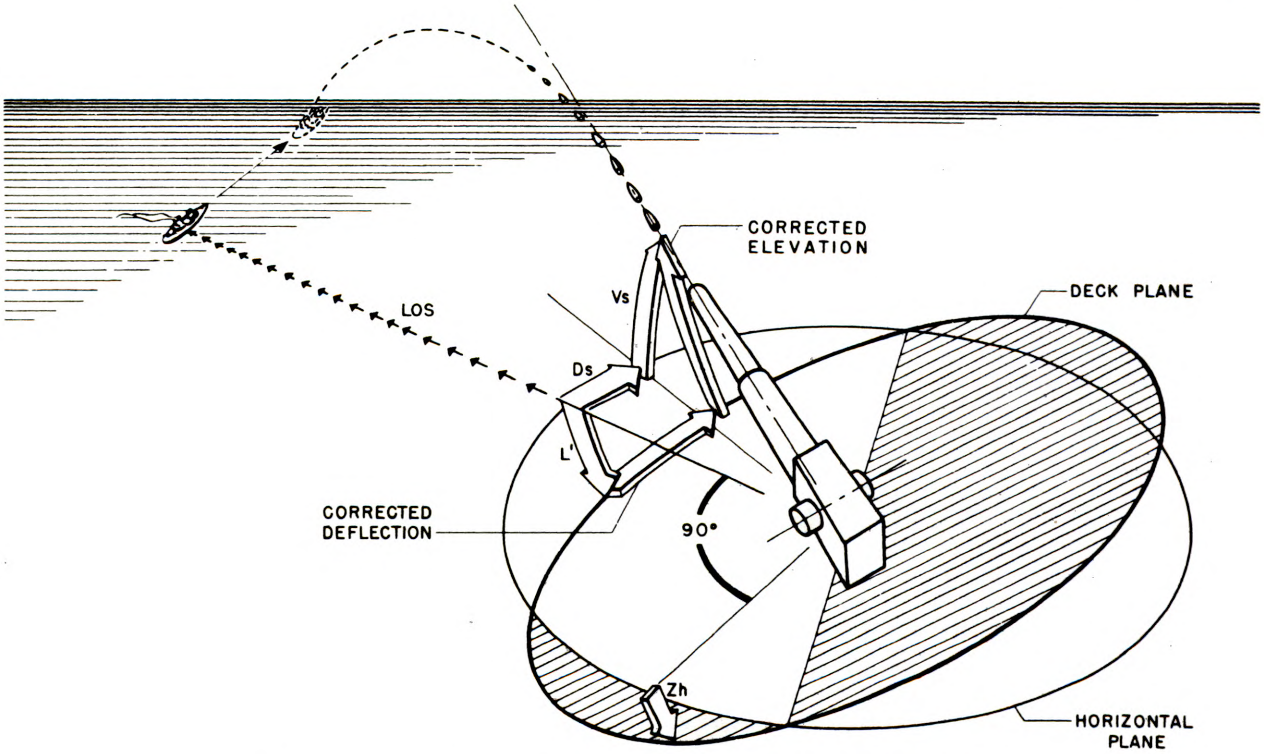

FIGURE 19B6.—The effect of trunnion tilt on train and elevation.

19B13. Corrections for trunnion tilt

Even though trunnion-tilt errors are shown in the vertical and horizontal planes, the gun is limited in its movement to training in the deck plane and elevating in a plane perpendicular to the deck. Consequently, the corrections must be calculated in the deck and perpendicular planes. As the deck is tilted, the gun barrel describes the surface of a cone the axis of which is the LOS. To return the barrel to a position parallel with its former position in space, the mount must be trained in the deck plane, which is now inclined, and elevated or depressed in a plane perpendicular to the deck. As the mount is trained, the gun barrel will follow the surface of a cone the axis of which is perpendicular to the deck.

Figure 19B5 shows the necessary corrections. Applying the required correction by training left is training "uphill," so that the bore axis would actually move above its original position. Therefore, it is necessary to depress the gun. It is evident that errors resulting from trunnion tilt cannot be corrected by applying equal and opposite amounts of gun train and elevation. Rather, it is necessary to compute the amount of movement in and perpendicular to the deck plane.

The mathematical solution of this problem is involved, and will not be included in this text. However, figure 19B6 shows how trunnion tilt corrections ensure that the gun will be offset from the LOS by *Vs* and *Ds* when the deck is inclined. The only practicable method of correction for trunnion tilt is by mechanical means, which will be discussed later.

19B14. Computation of gun orders

In modern gunnery, the gun battery is positioned to hit the target by training the guns to a certain angle relative to the fore-and-aft axis of the ship, and elevating them to a certain angle relative to the reference (deck) plane. These angles are known as *gun train order* and *gun elevation order*. Gun orders are computed mechanically in the rangekeeper (or computer). They are composed basically of (1) the bearing and elevation of the line of sight to the target (measured or generated), (2) the sight angle and sight deflection, and (3) the corrections for trunnion tilt. The orders are transmitted electrically to the guns, where they are used either to position the guns automatically or to position dials which may be followed by the pointer and trainer at the mount, as they position the guns.

The values of sight angle and sight deflection are also transmitted to the guns, where they are set on the gun sights. This provide a secondary method of positioning the guns, using the local telescope line of sight. With this method, no correction for trunnion tilt is included.

19B15. Correcting the fall of shot

Regardless of the accuracy of all computations, an error in the fall of shot may still exist. For example, information on which the calculations are based may not be completely accurate. These errors must be corrected by spotting the salvos to the target. The methods of spotting have been covered in the preceding chapter.

C. Graphic Rangekeeping

19C1. The Mark 2 plotting board

In the analytical solution (sec. 19B), target motion and own-ship motion in the LOS were calculated mathematically and combined into range rate. The same range rate may be determined by graphic analysis.

In 1911, the Mark 2 plotting board (fig. 19C1) was introduced and became an important part of the main-battery fire control system. In modern fire control systems the functions of the plotting board are performed by rangekeepers and their automatic *graphic plotters*. However, an explanation of the operation of

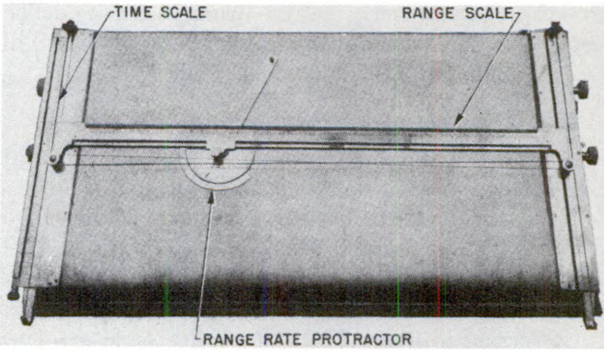

FIGURE 19C1.—Plotting Board Mark 2.

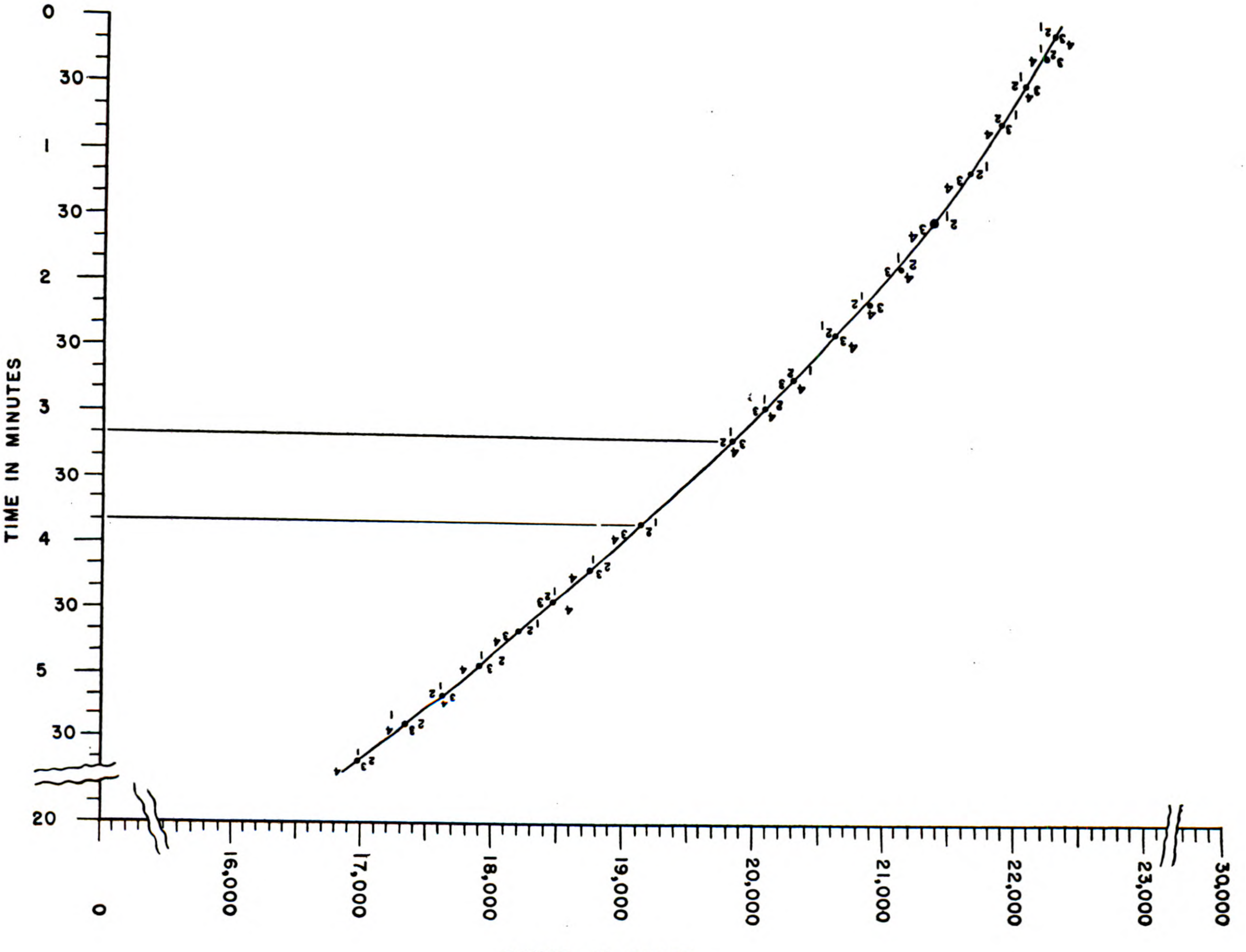

FIGURE 19C2.—Plot of a mean range line.

the plotting board at this time will serve to demonstrate the fundamentals of all graphic rangekeeping.

The plotting board was designed to keep present range and to predict range for short intervals. It also provided a means of determining range rate, applying ballistic corrections and spots to obtain sight-bar range. It still is used to furnish a convenient method of keeping a time record of the firing, including deflection settings, spots applied, and times of salvos. This record is invaluable for post-firing analysis.

19C2. Principle of graphic plotting

If range is plotted against time, a series of points will be developed which may be connected to form a curve. If the points represent the mean of the ranges of several rangefinding instruments (as in fig. 19C2), the resulting curve is known as the *mean range line.* This is a graphic means of keeping the range.

Referring to figure 19C1, the range scale is moved downward at a fixed time rate. Ranges plotted along the range scale provide the points which are connected to form the mean range line. If ranging is interrupted for a short interval of time, the mean range line may be continued (or advanced) with little or no loss in accuracy. This has occurred from 3 minutes 10 seconds to 3 minutes 50 seconds in figure 19C2.

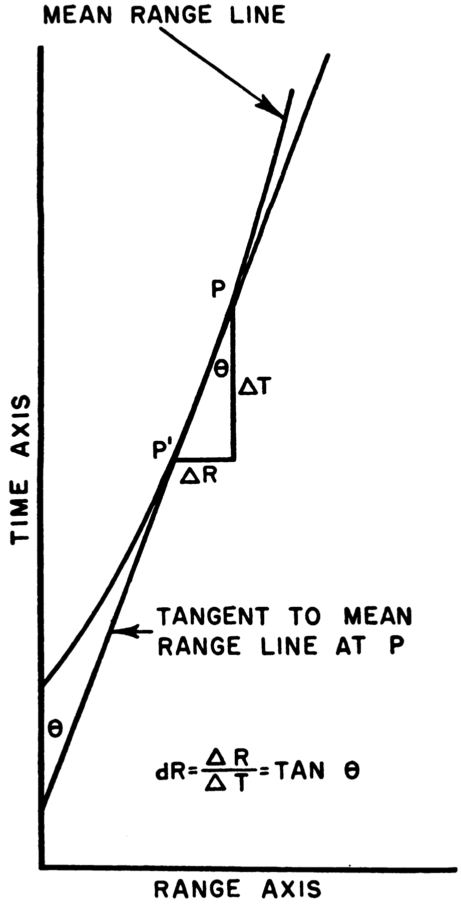
MEAN RANGE LINE
P
θ
ΔT
P'
ΔR
TIME AXIS
TANGENT TO MEAN RANGE LINE AT P
θ
$dR=\frac{\Delta R}{\Delta T}=\text{TAN } \theta$
RANGE AXIS

FIGURE 19C3.—Range rate; the slope of a mean range line.

19C3. Range rate

An inspection of figure 19C2 reveals that if the mean range line slopes downward to the left, as in this case, the range is *decreasing.* The result is a decreasing or *negative* range rate. Conversely, if the mean range line were sloping downward to the right, the range rate would be increasing or positive.

The amount of slope at any point with respect to the time axis is a direct indication of the instant range rate at that time. More accurately stated, range rate varies directly as the tangent of the angle formed by a line tangent to the mean range line and the vertical (time axis). This is illustrated in figure 19C3.

As observed in article 19B7, $\Delta R=dR\times\Delta T$; or $dR=\Delta R\div\Delta T$. In the figure, ΔR is the change in range and ΔT is the time interval between points P and P′. The angle between the tangent and the vertical is θ. Assuming that the time interval under discussion is small so that P and P′ are on the tangent as well as on the mean range line, then $\tan\theta=\Delta R\div\Delta T=dR$. Thus, it is only necessary to measure θ, and dR can be determined from $\tan\theta$. The protractor on the Mark 2 plotting board measures θ. Its scale is so graduated that it reads the value of dR in knots corresponding to the value of θ which it measures.

Range rate determined in a similar manner on the graphic plotter of the modern rangekeeper is used to check the range rate generated by the rangekeeper. This will be explained in chapter 20.

19C4. Gun-range line

It is convenient to represent sight-bar range on the plotting board by means of a *gun-range* line, so named to distinguish it from the mean range line. Sight-bar range is the range shown on the sight scale of the gun at the instant of firing. It is the algebraic sum of present range, total ballistic correction, and range spots.

The total range ballistic correction may be calculated by means of a ballistic computation sheet. This ballistic correction is applied graphically to the mean range line on the plotting board. The result is the gun-range line, a second line which is drawn parallel to the mean range line. This gun-range line is offset as necessary whenever a spot is applied, and then continued parallel to the mean range line. The gun-range line furnishes sight-angle settings (in the form of sight-bar ranges) to the gun.

With this system there is of necessity a delay between the time the plotter decides to transmit a sight-

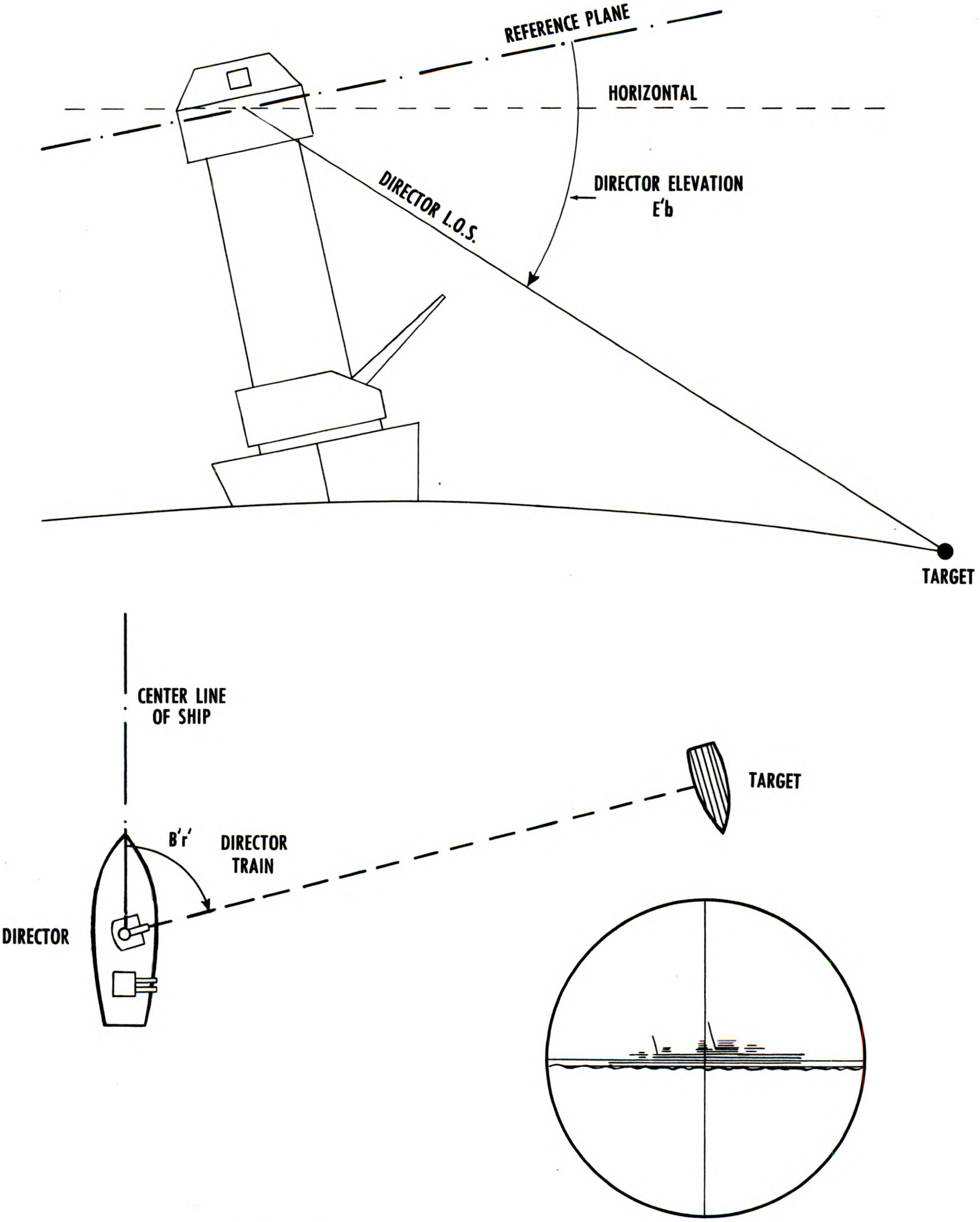

FIGURE 19D1.—The director measures bearing, elevation, and range.

bar range to the gun and the time the gun actually fires with this sight setting. The appropriate sight-bar range must be picked from the plot, transmitted to the gun, and set on the sights; and the gun must be fired. The period of time required for these actions is called *dead time*. This problem is solved by the plotter, who mentally advances the gun-range line by an amount equal to the dead time (determined by experience). He then picks off the sight-bar range corresponding to the time at which the guns will fire, and this value is transmitted to the guns.

It can be seen from the above discussion that the graphic solution of the fire-control problem is slow, difficult, and inexact in many ways. In the modern fire-control system, the graphic plot is used only as a check on the range rate generated by the rangekeeper.

D. Mechanical Solution—General

19D1. System elements

The principal components of a fire control system are the gun director, the computer (or rangekeeper), the stable element (or stable vertical) and the gun mount, with essential transmission and communications equipment. All these components are aligned, upon installation, with the fundamental reference planes of the ship, and are maintained in proper alignment by frequent checks.

The gun director is located high in the ship's structure, to get away from smoke and other interference and to provide as distant a horizon as practicable. The director may be rotated to any desired point in bearing, and the optical sights and radar antenna contained in it can be elevated within desired limits. By means of optical equipment and radar, the director is able to measure (1) the range to the target, (2) the relative bearing of the target, as an angle in the deck plane, measured clockwise from the bow, to the perpendicular plane through the line of sight, and (3) the elevation of the target as an angle above the deck plane. Ordinarily, the latter is measured by the stable vertical or stable element. The last two quantities are called director train and director elevation.

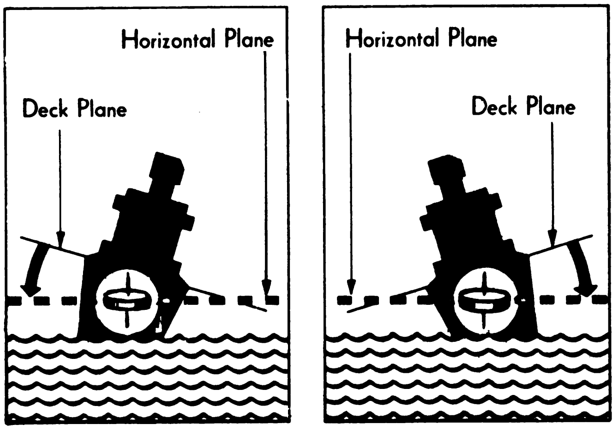

FIGURE 19D2.--The stabilizing equipment measures inclination of the deck.

In other words, the director establishes the line of sight to the target, and measures three aspects of the line of sight to form the basis of the problem: range, director train, and director elevation. These quantities are transmitted continuously to the computer. In addition, other values—chiefly estimated target speed and target angle—are transmitted from the director to the computer.

The computing instrument is located below decks. Its functions are to take the inputs from the director, plus additional information from other sources, such as own ship's speed from the pitometer log, own ship's course from the gyro compass, and the mechanical inputs from the stabilizing equipment; to combine these, computing the predicted position of the target and applying corrections; and to transmit the results to the guns as gun train order and gun elevation order.

The stabilizing equipment uses a gyroscope to measure the inclination of the deck plane with respect to the horizontal, resolves the deck tilt into components in and across the line of sight, and transmits this information to the computing instrument and to the director.

The gun is, of course, the striking force of the whole system. It is ordinarily equipped with automatic control equipment, including the necessary receivers to pick up the gun orders from the computer. The automatic control equipment points the guns by turning the whole mount in train and moving the guns themselves in elevation.

It may be helpful, in remembering the primary functions of the equipment, to think of the director as the eyes of the system, the computer as the brain, and the gun as the fist.

19D2. Reference systems

Since the fire control system is composed of many units installed at various places on the ship, sometimes at considerable distances both horizontally and vertically, it is necessary to install all the units in a consistent alignment and to make frequent checks to ascertain that proper alignment is maintained. The problem of establishing a reference system is covered in

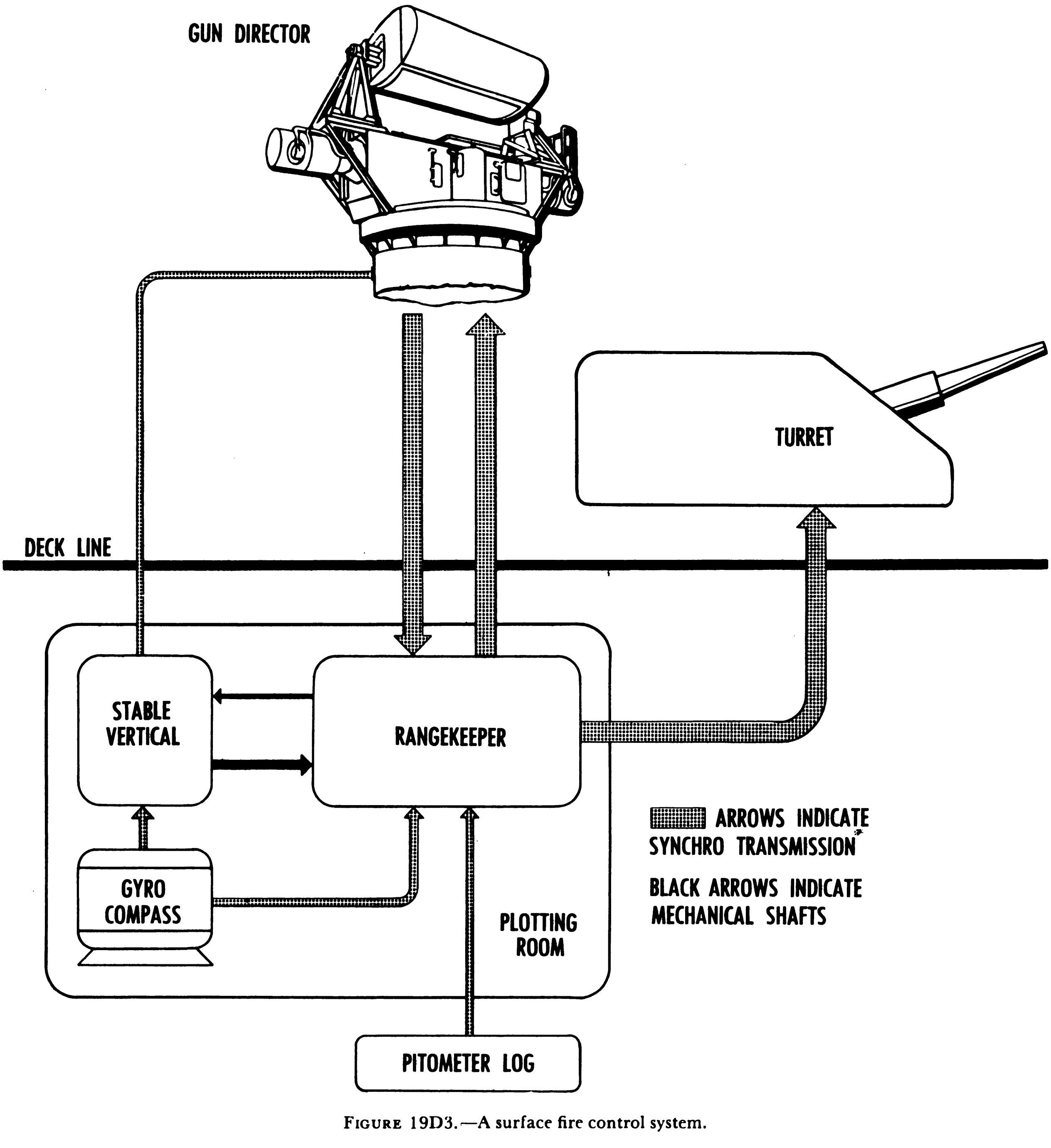

FIGURE 19D3.—A surface fire control system.

detail in chapter 21, Battery Alignment; the problem of correcting for horizontal and vertical displacement is treated in the next article.

19D3. Parallax

Figure 19D4 shows a typical installation with guns forward and aft and an amidships director. It shows that if a value of gun train order is based on the LOS from the director, a convergence correction is needed at the guns if they are to hit the target. This correction is called horizontal (or train) parallax, as it is caused by displacement in the horizontal and gives rise to an error in train.

If there is only one director, parallax does not enter

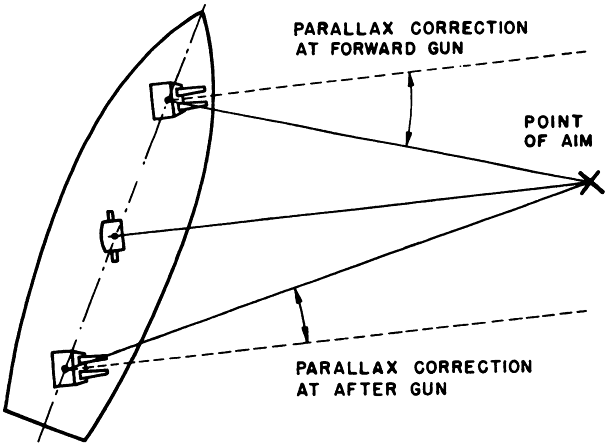
PARALLAX CORRECTION AT FORWARD GUN
POINT OF AIM
PARALLAX CORRECTION AT AFTER GUN

FIGURE 19D4.—Effect of parallax on gun train.

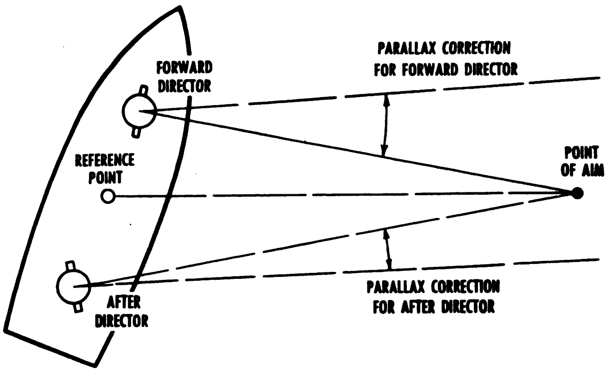
FORWARD DIRECTOR
PARALLAX CORRECTION FOR FORWARD DIRECTOR
REFERENCE POINT
POINT OF AIM
AFTER DIRECTOR
PARALLAX CORRECTION FOR AFTER DIRECTOR

FIGURE 19D5.—Effect of parallax on director train.

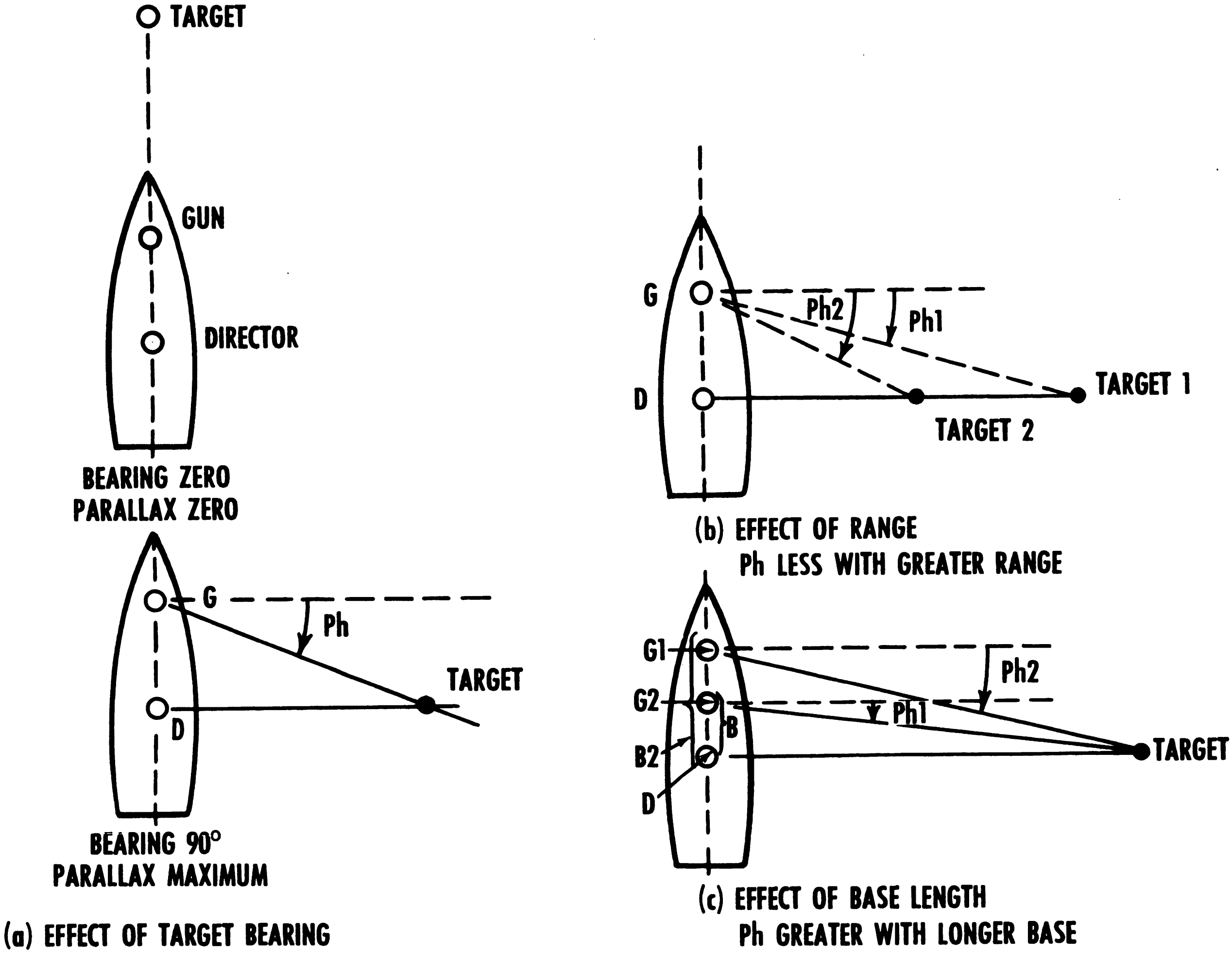

FIGURE 19D6.—Effect of bearing, range, and base length on horizontal parallax *Ph*.

into the value of director train. However, if there are two directors which are to be used interchangeably, as illustrated in figure 19D5, it is clear that the actual train angle of the two directors will differ by the amount of horizontal parallax. One director can be chosen as the reference point in train and the reading of the other director corrected to it, or a reference point can be chosen midway between the directors and the reading of both corrected to that reference.

In computing horizontal parallax, it can be seen from figure 19D6 that the value depends on a number of factors:

1. *The horizontal base length.* The actual distance in the deck plane between the reference point and gun or reference point and director. This is a fixed quantity.
2. *The range.* Parallax varies inversely with range.
3. *The bearing.* In correcting both guns and directors for horizontal parallax, the quantity actually used is gun train or director train in the deck plane. When on target, these quantities would be equal to $B'gr$ and $B'r'$ respectively.

The general expression for horizontal parallax is:

$Ph = b \sin \phi \times 1/R$, where

Ph is horizontal parallax angle,

b is the base length,

ϕ is the train angle of the element (*i. e.,* $B'gr$ or $B'r'$),

R is range.

Mechanically, the quantity is multiplied by the reciprocal of range, which can easily be done, rather than divided by range, which is more difficult.

In some systems the computer works out the correction for a standard horizontal base length of 100 yards and transmits it to the guns. Gears at the gun or director in ratio of actual base length and standard base length are used to pick off the proper proportion of the correction. For instance, an element 50 yards from the reference point would need only half of the correction, as its own base length is half the standard. In other systems range, or a function of range, is sent to each gun and director, and similar corrections are worked out in computing devices located at each station.

Vertical parallax (Pv) depends on the range and the vertical displacement between the gun and the director.

E. Basic Mechanisms

19E1 Introduction

The study of any computer should be based on an understanding of the various basic mechanisms of which it is composed. These devices perform the mathematical computations essential to solution of the fire control problem. The present discussion will be limited to the most important basic mechanisms.

Mechanisms are represented by conventional symbols which facilitate their presentation on functional diagrams. Since the understanding of such diagrams is essential to the officer performing gunnery duties, these symbols are included in the figures depicting each mechanism.

19E2. Shafts

The computer receives inputs, performs computations, and transmits outputs. These quantities are in various units such as yards of range, degrees of elevation, knots of ship speed. Since, however, each of these quantities can be expressed as a number, it is possible to translate all quantities to shaft rotation. This procedure not only provides mechanical representation of the quantity; it also makes it easy to change or modify the quantity by suitable rotation. As the value of an input (such as own-ship speed) changes, the values of the computed quantities will change accordingly. These changes must be carried instantaneously and continuously to all the mechanisms affected by the change of input. These changing values are carried from one mechanism to another by shaft rotation.

Turning a shaft changes the value of the angle, speed, or distance represented by the position of that shaft. Rotation in one direction increases the value represented, and is considered positive; rotation in the other direction decreases the value, and is negative. From this, it follows that every shaft has a zero position, even though, as is sometimes true, the shaft may be restrained from reaching the zero position.

One revolution of a shaft can represent any convenient amount of change in the given quantity. For example, one revolution of the elevation shaft may represent a 3° change in elevation. On a range shaft, one turn may represent 100 yards of range. The value that a shaft carries in one revolution is called *shaft value.* Total value carried by a shaft is the shaft value multiplied by the number of revolutions made by the shaft from its zero position.

It is sometimes necessary to add or subtract a constant from a value carried by a shaft. For example, in the computer the value of range minus a constant is used. In this instance the crank input is range, but the mechanism is positioned for range

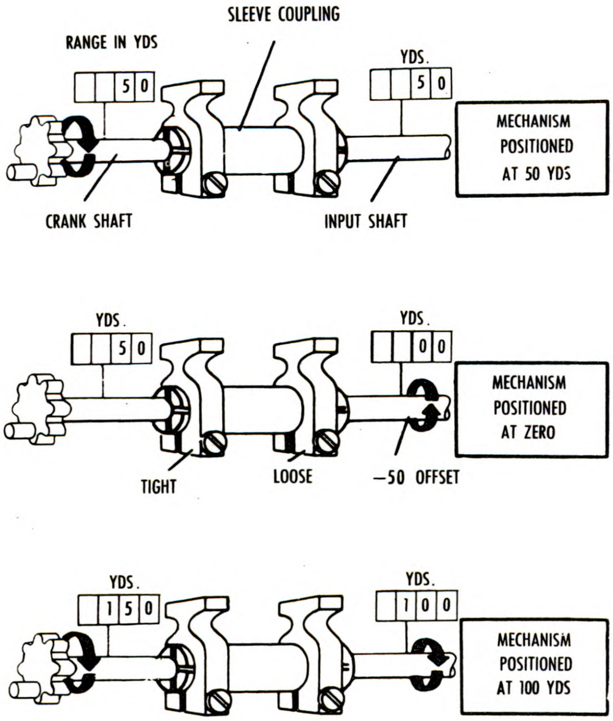

FIGURE 19E1.—A coupling used to introduce a constant.

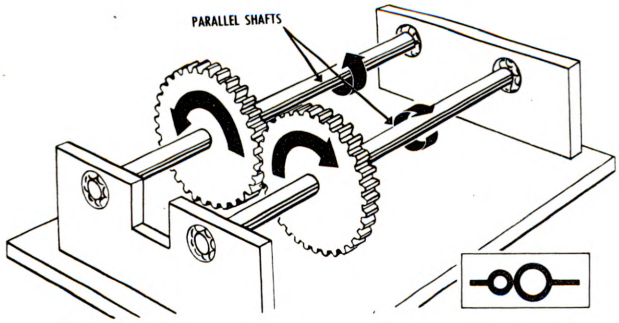

FIGURE 19E2.—Spur gears.

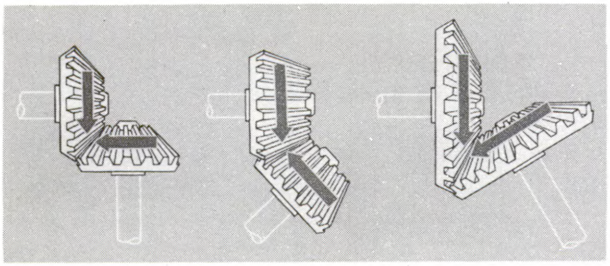

FIGURE 19E3.—Bevel gears.

minus *K*. The constant *K* can be set into the transmission line by a sleeve coupling or a clamp, as is shown in figure 19E1. Here a sleeve coupling joins two shafts which must introduce into the mechanism range in yards minus a constant of 50 yards. Each shaft has a counter showing its position. Both shafts are initially positioned at 50 yards. If one clamp is loosened, the input shaft can be turned until its counter reads zero without moving the crankshaft. If the clamp is now tightened, with the value of 50 yards on the crankshaft and zero on the input shaft, the two shafts will turn together when the crank is turned, but the input to the mechanism will always be 50 yards less than the crank input. This use of a clamp is called "putting a constant offset on the line." The offset can be *plus* or *minus*.

19E3. Gears

Gears are wheels with mating teeth cut so that one can turn the other without slipping. If two mating gears are the same size, they will have the same number of teeth. One revolution of the driving gear will turn the driven gear one revolution, because each tooth of the driving gear will push one tooth of the driven gear across the line between their centers.

If two gears are of different sizes, the smaller one is usually called a pinion. When a gear and a pinion mesh together, their shafts turn at different speeds. If the gear has twice as many teeth as the pinion, one revolution of the driving gear will turn the pinion two revolutions.

The ratio between the number of teeth on the driving gear and the number of teeth on the driven gear is called the gear ratio. Gear ratios are often used for no other reason than to change the shaft values, by multiplication or division. If a shaft has a value of 500 yards per revolution, this can be reduced to 50 yards per revolution by a 1:10 gear ratio.

Although there are many different types of gears, most of those used in fire control installations are of three types: spur gears, bevel gears, and sector gears. *Spur gears* are used to connect parallel shafts and have the teeth cut parallel to the axis of rotation, as in figure 19E2.

Bevel gears can be designed to transmit motion between shafts at almost any angle to one another, as is indicated in figure 19E3. By using bevel gears, several shafts at different angles can be driven by one driving shaft.

Sometimes only a part of a gear is needed, where the motion of the pinion is limited. In this case, space is saved by the use of a *sector gear,* illustrated in figure 19E4. A special type of sector gear is the *rack,* frequently used to convert rotary motion to linear motion. A rack is a straight bar with gear teeth cut in it, as shown in figure 19E5. If the rack drives a gear, it converts linear motion into rotary motion. The rack is restrained by guide rails which permit motion in one line only. The position of a rack indicates a value by the amount it has moved from zero.

It must be understood that motion of a shaft, rack, gear, or dial has no meaning except that assigned by the designer. It is not difficult to design an assembly so that proper values are entered and transmitted. For example, the conversion constant 0.563, which converts knots to yards per second, is applied by a gear ratio. (A close approximation can be obtained by a gear ratio of 22:39, which equals 0.564.) The mechanism shown in figure 19E6 will serve to illustrate some of the principles presented in this section. The sequence starts with an input shaft, one turn of

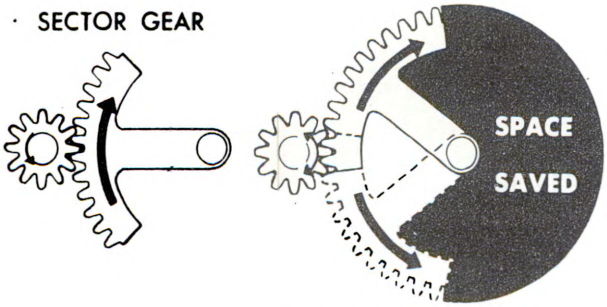

FIGURE 19E4.—Sector gears.

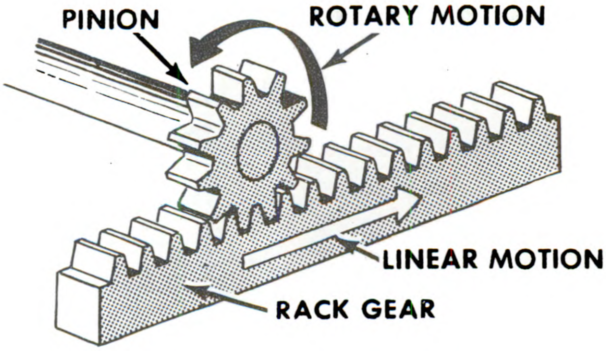

FIGURE 19E5.—Rack and pinion.

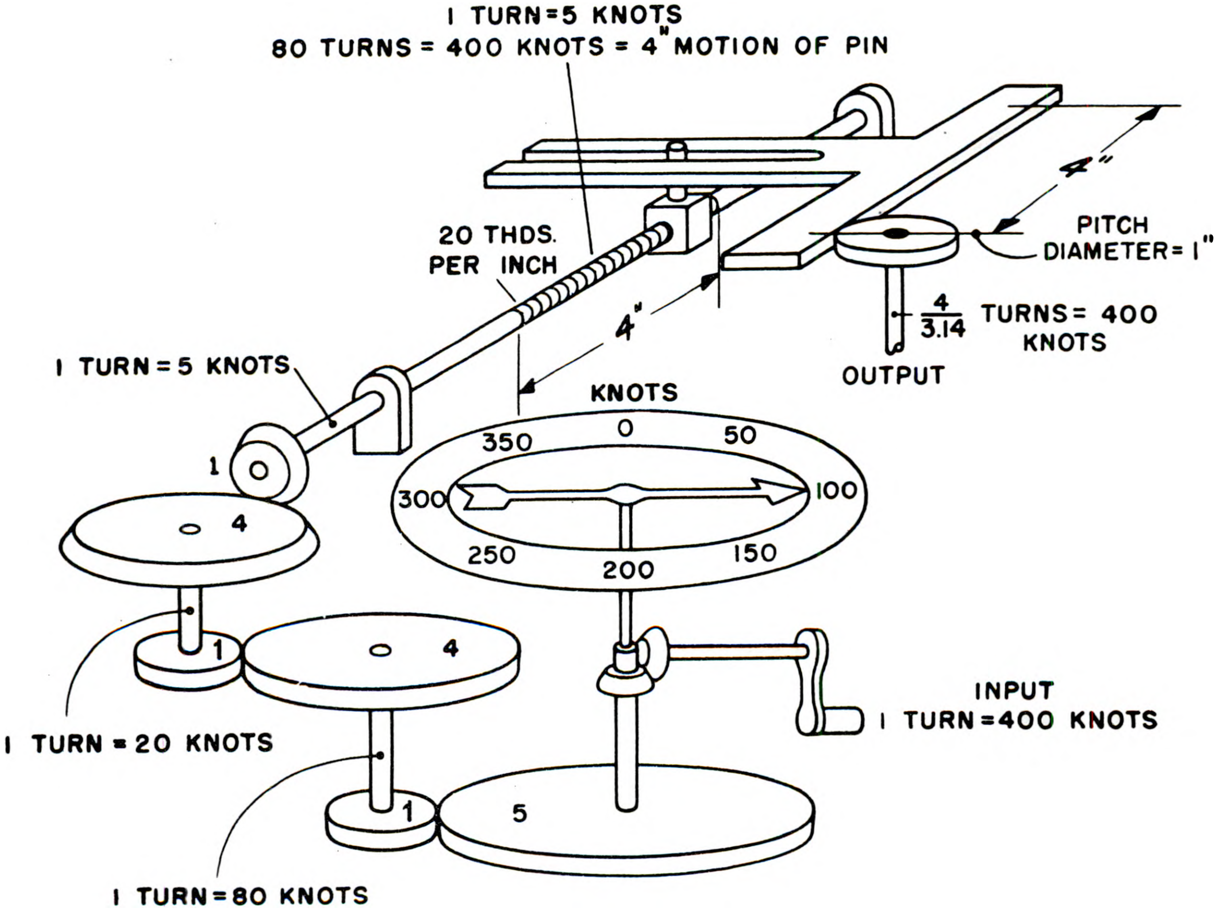

FIGURE 19E6.—Values of shaft rotation.

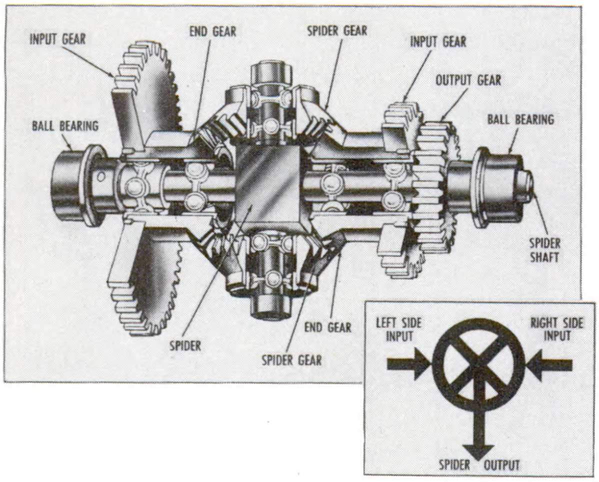

FIGURE 19E7.—The differential.

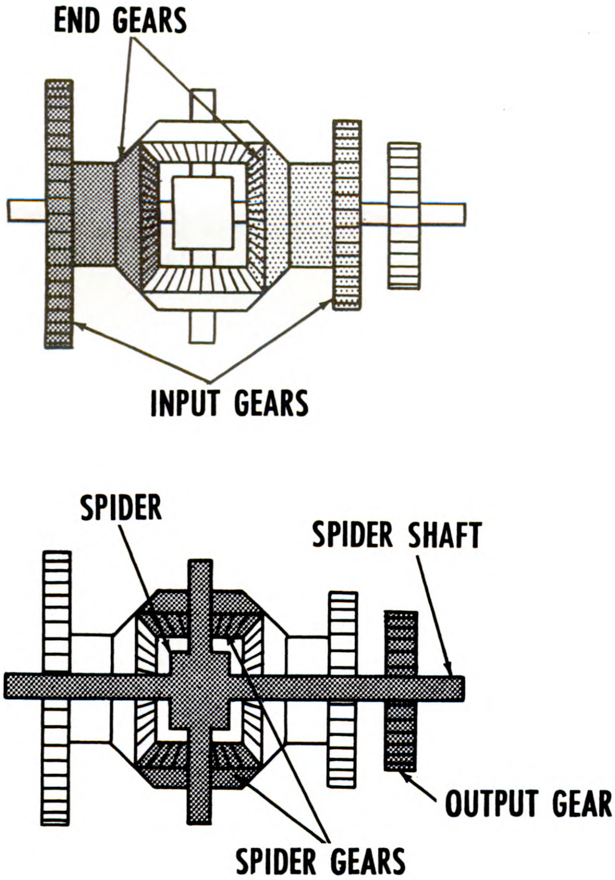

FIGURE 19E8.—The differential: end gears and spider arrangement.

which represents 400 knots. The ratios of the gears have been designed to use the 4-inch motion of the rack, which is driven by a screw with 20 threads to the inch. Since each revolution of the screw shaft represents 5 knots, each inch the screw (and therefore the rack) moves equals 100 knots, and 4-inch travel of the rack represents 400 knots. It is possible to transform the output of the rack (linear motion) to shaft rotation as shown. If an output shaft carrying a gear with pitch diameter of 1 inch is used, one revolution of this output shaft will represent $\pi \times 1$ inch, or 3.14 inches of linear motion of the rack. The value $\frac{4}{3.14}$ turns of the output shaft will then represent 400 knots.

19E4. Differentials

A differential is a mechanism that can perform addition and subtraction. More precisely, it adds the total revolutions of two shafts or subtracts the total revolutions of one shaft from the total revolutions of another shaft, and delivers the answer by positioning a third shaft.

A differential will add or subtract any number of revolutions, or fractions of single revolutions, continuously and accurately. As inputs change, it produces a series of answers.

Figure 19E7 is a cut-away drawing of a bevel-gear differential, showing the relation of all its parts. Grouped around the center of a mechanism are four bevel gears, meshed together. These four gears and the spider shaft are the heart of the differential.

The two bevel gears on either side are the *end gears;* the two bevel gears above and below, meshing with the end gears, are the *spider gears*; the cross shaft and the spider gears constitute the *spider,* and the long shaft to which the cross shaft is pinned is the *spider shaft*. All gears are free to rotate on precision bearings.

The three spur gears in figure 19E8 are used to connect the two end gears and the spider shaft to other mechanisms. They may be of any convenient size. The two attached to the end gears are normally *input* gears. An input gear and an end gear together make up a *side* of the differential.

The output gear is pinned to the spider shaft. It is the only gear in the mechanism that is pinned directly to a shaft.

Figure 19E9 shows how the spider gears work. The two end gears are positioned by the input shafts, which represent the quantities to be added or subtracted. The spider gears are driven by the two end gears, turning the spider shaft a number of revolutions proportional to the sum or the difference of the revolutions of the end gears.

Suppose the left side of the differential is rotated while the other is held stationary. The moving end gear will drive the spider gears, making them walk around the stationary end gear. This motion rotates the spider in the same direction as the input, and turns the output shaft with it. The output shaft will turn a number of revolutions proportional to the input.

If the right side is now rotated and the left side held stationary, the same thing will happen. If both sides of the differential are turned in the same direction at the same time, the spider will be turned by both at once. The output will be proportional to the sum of the two inputs. Actually, the spider makes only half as many revolutions as the sum of the revolutions of the end gears, because the spider gears are free to roll between the end gears. Of course, the answer can be corrected by using a 2:1 gear ratio between the output shaft and the next mechanism in the line.

When the two sides of the differential move in opposite directions, the output on the spider shaft is proportional to the difference of the revolutions of the two inputs. This is because the spider gears are free to turn, and are driven in opposite directions by the two inputs. If the two inputs are equal and opposite, the spider gears will turn, but there will be no movement of the spider shaft.

19E5. Cams

Gears can be used to convert one value to another when they are directly proportional. Differentials can add or subtract quantities represented by shaft rotation. However, in the fire control problem there are other functions which vary in a more complex manner. For example, drift and time of flight are functions of range, but not in direct proportion. Examination of the range table for the 5″/38 caliber gun will show that the value of drift for a range of 5,000 yards is 10 yards, but the value of drift for 10,000 yards is 69 yards, considerably more than twice the value at 5,000 yards.

To obtain the correct mechanical output of drift for the values of range, a *cam* is used. A cam is a rotating or sliding device whose operating surface is cut to give the desired output for every value of input. The output is taken off by a *cam follower*. The follower may ride in a groove or slot in the cam face, or it may ride on the outside contour of the cam.

One simple cam has a uniform or *constant-lead* spiral groove cut in the face of a disc as shown in figure 19E10. Each point on the spiral corresponds to an output that is directly proportional to the input.

If the constant-lead cam is rotated in one direction, the spiral will force the follower block outward from the center along a straight slot. Turning the plate in the opposite direction forces the follower toward the

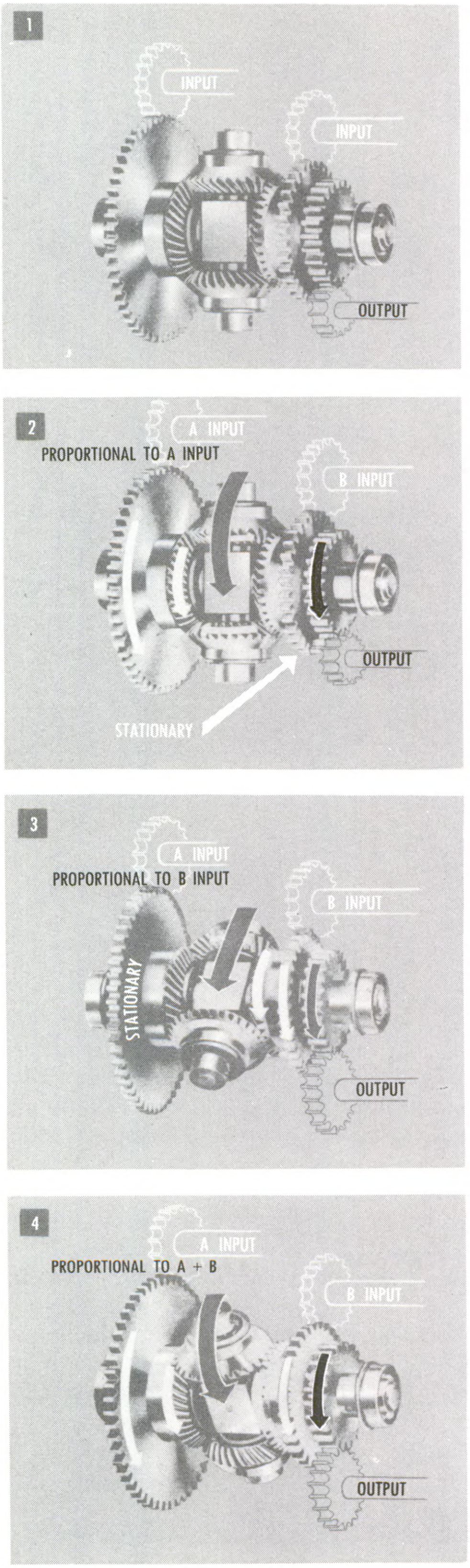

FIGURE 19E9.—How a differential works.

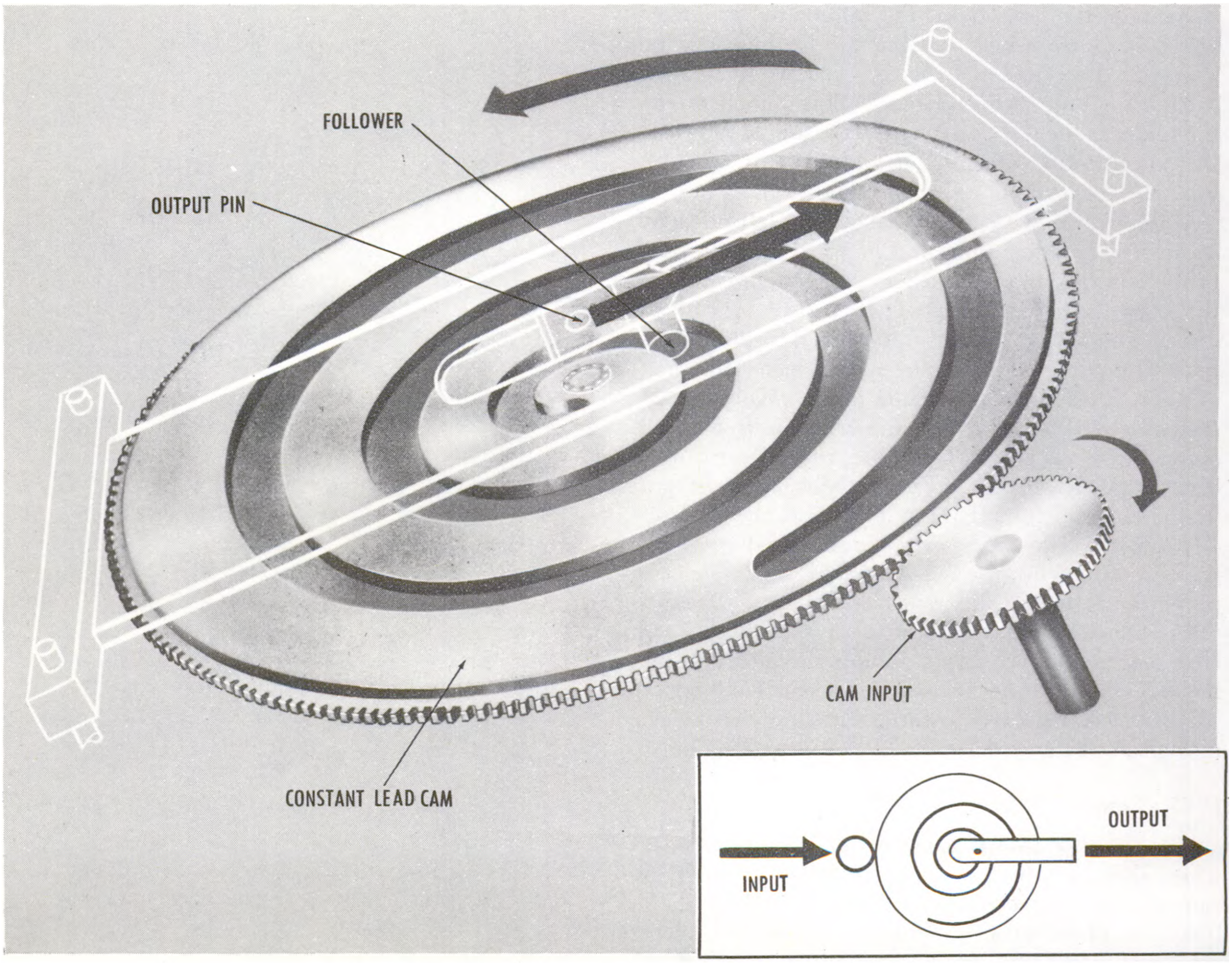

FIGURE 19E10.—Constant-lead cam (positive motion).

center. The follower itself never travels to the center of the cam, but the output pin is offset on the follower block so that it can be positioned directly over the center of the cam for the zero position. The cam output is the distance from the center of the cam to the output pin, and can be picked off by a slide or rack. The output of the constant-lead cam is directly proportional to the input.

In other cams, each point on the output surface represents a more complex function, such as the reciprocal, the square, or some empirical function. Such cams are called *computing cams* to set them apart from the constant-lead type. Most cams used in computers are computing cams.

In the flat ballistic cam illustrated in figure 19E11, the edge of the cam does the computing. The cam is fixed to the cam gear and turns with it. A roller on the sector follower arm is held against the edge of the cam by a spring at the bottom of the arm. The distance from the center of the cam gear to the edge of the cam surface is designed to give the desired functional relationship. The movement of the roller pivots the sector arm which turns the output gear.

When the cam is so constructed that motion of the follower will positively result when the cam plate is moved, it is called a *positive-motion* type of cam. In the *non-positive-motion* type the follower is held against the cam surface by some acting force such as a spring or gravity. Figure 19E10 is an example of the positive-motion type, while figure 19E11 illustrates the other type.

19E6. Reducing cam displacement

If a cam is cut to supply the full value of a function of a variable, it must necessarily be fairly large to provide accurate outputs. The size of the cam (and thus the ultimate size of the computer itself) can be greatly reduced if it is made to supply only a part of that function. This result can be obtained with the *partial-correction cam* which makes use of a *straight-line approximation.*

Assuming that it is desired to compute sight angle Vs by a cam, refer to figure 19E12. The true sight-angle curve is plotted in the figure with advance range $R2$ as the abscissa and sight angle Vs as the ordinate. A sample computation is represented graphically in the figure. At a given advance range $R2$, the corresponding sight angle Vs can be found from the graph by moving vertically from the value of advance range to the sight-angle curve. However, the actual cam is cut to produce not Vs, but the quantity labeled "cam correction" on the curve, jVs[*] on the diagram to the

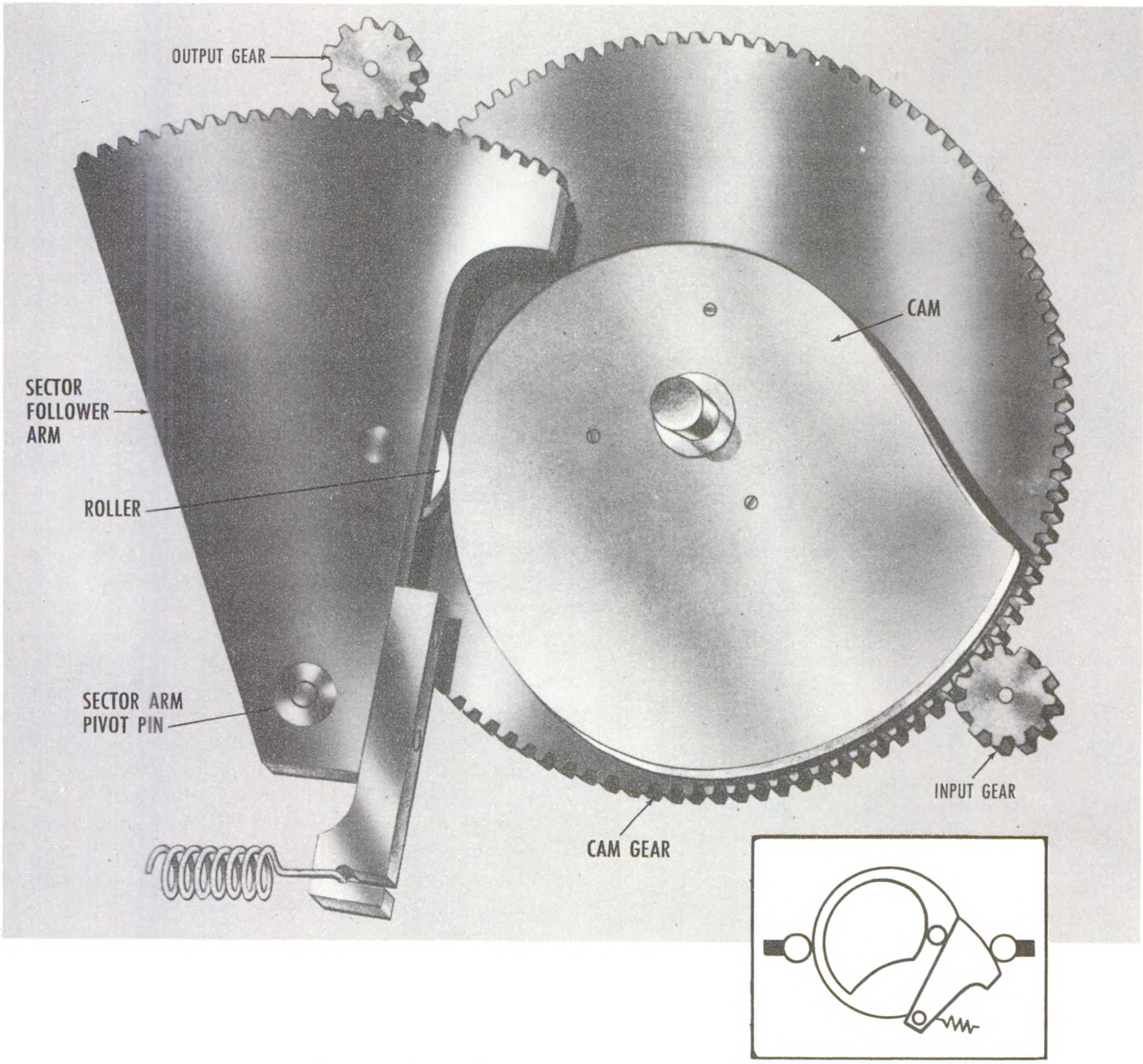

FIGURE 19E11.—Flat ballistic cam (non-positive motion).

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[*] The symbol j before a quantity, as used here, will be encountered frequently. As defined in the appendix, "Before a quantity it means a correction or partial correction to that quantity, usually generated by the mechanism; after the quantity it means an arbitrary correction (spot) to that quantity." In mechanical computers, j is used before a quantity with two distinct meanings, first, as in present range (jR), in the sense of an *initial or corrective setting* and second, as in the present case, the output of the partial-correction cam, where it expresses a *partial* value of the quantity—a value to which something else must be added to obtain the complete quantity.

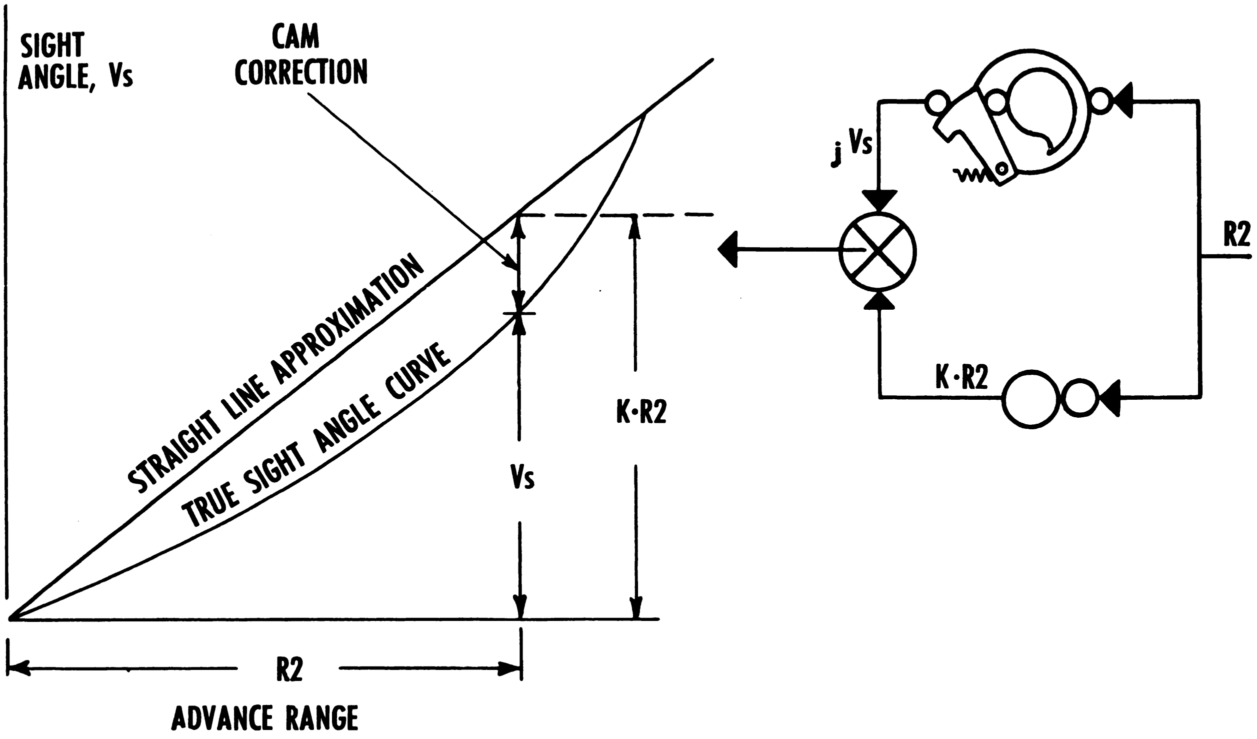


FIGURE 19E12.—Theory of partial-correction cam.

right. This correction is the difference between the true sight-angle curve and the straight-line approximation of the curve. Since the straight line has constant slope, its ordinate at any given value of *R*2 is equal to a constant *K* times *R*2 (*KR*2). This multiplication can be accomplished by a gear ratio, as indicated.

The value of *KR*2 is then combined with the corresponding value of cam correction in a differential, as shown in the figure. The output of this differential will then be the value of *Vs* for the given *R*2. In other words, $Vs = jVs + KR2$. With this arrangement, the size of the cam is greatly reduced.

19E7. Component solvers

The component solver is a device for resolving a vector into components with respect to a reference line. In the analytical solution of the fire control problem, it was shown that own ship, target, and wind motions are represented by vectors and resolved into components in and across the line of sight.

The component solver which resolves own ship's motion into *Yo* and *Xo* is shown in figure 19E13. The dial carrying the compass rose and own-ship outline is free to rotate. The vertical pin may be moved in the radial slot. Two reference lines are shown, the vertical one representing the line of sight.

The center of the vertical pin corresponds to the arrowhead of a vector representing the motion of own ship. The distance of the pin from the center of the dial represents own-ship speed (*So*). The angular position of the radial slot with respect to the line of sight corresponds to relative target bearing. If *Br* and *So* are properly set, the displacement of the pin from the reference lines will be a measure of *Xo* and *Yo* to the same scale as that used for setting *So,* as shown in the small triangle. Inspection will show that the component solver solves the equations $Xo = So \sin Br$ and $Yo = So \cos Br$.

Figure 19E13 shows the arrangement for picking off the outputs. The range slide is mounted so that it moves only parallel to the LOS, while the deflection slide moves perpendicular to the LOS. The vertical pin extends below the dial and fits in the slots of the slides. Thus, as the pin is moved, the slides are driven the amounts shown against the *Xo* and *Yo* indices. In the actual computer, the scales are replaced by gear teeth to form racks meshed with spur gears rotated by the *Xo* and *Yo* outputs respectively.

Component solvers used in computers differ in details but operate according to the same principle. Figure 19E14 shows the type now in general use for resolution of ship, target, and wind motions.

The dials indicating the speed and angle setting are on the face of the computer, separated from the actual

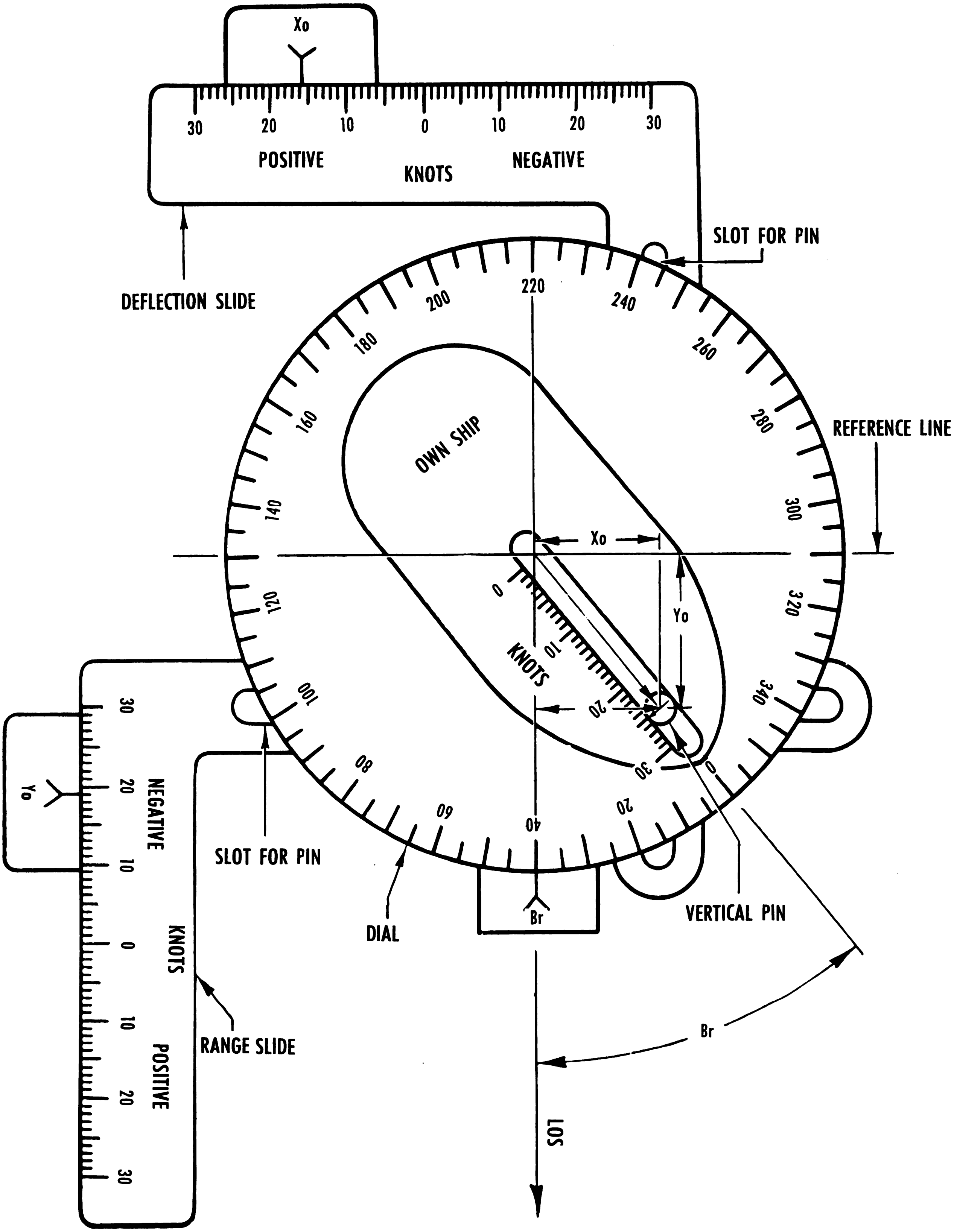


FIGURE 19E13. —Principle of the component solver.

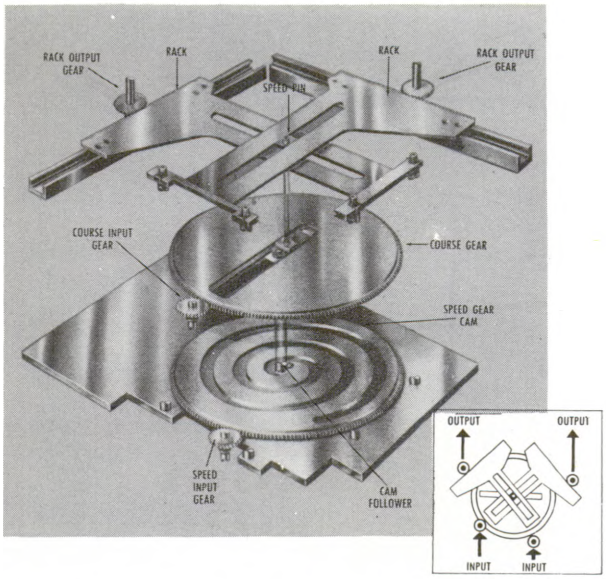


FIGURE 19E14.—Exploded view of a component solver.

component solvers but connected by suitable shafts and gears. The position of the course gear determines the direction of the vector with respect to the reference line. The radial position, or speed setting, of the pin is controlled by the spiral groove in the speed gear. When the speed gear is rotated with respect to the course gear, the spiral slot causes the pin to move in or out, setting the proper length of the vector representing ship's speed. When the speed and course gears are rotated together, and the speed setting is unchanged, there is no radial movement of the pin.

There is one possible error in a component solver of this design. If the course gear is turned to reset a vector while the speed gear is held stationary, the course-gear slot will cause the pin to move along the cam groove and introduce an incorrect setting of speed. Such errors are prevented by a differential in the cam input line, called a *compensating differential,* and illustrated in figure 19E15. Course setting drives one side of the differential. Speed setting drives the spider. The other side gear is used as the output to drive the speed gear. If there is no speed input, the spider is held stationary, and the course input drives through the differential to turn the speed gear the same amount as the course gear, thus preventing any change in speed. If there is no motion of the course input, the speed input drives through the spider to turn the speed gear without disturbing the course gear. The differential thus causes the speed gear to be turned by both course and speed inputs, while the course gear is turned only by course inputs, so that correct settings of one can be made without introducing error into the other.

19E8. Integrators

Integrators, as used in computers, perform a special type of multiplication. In the disc-type integrator, illustrated in figure 19E16, a constantly changing value, such as time, is multiplied by a variable such as range rate, the output being a continuous value of their product which can be accumulated as shaft rotation.

The instrument consists of a flat circular disc revolved at constant speed by a motor equipped with a clock escapement; a carriage, containing two balls

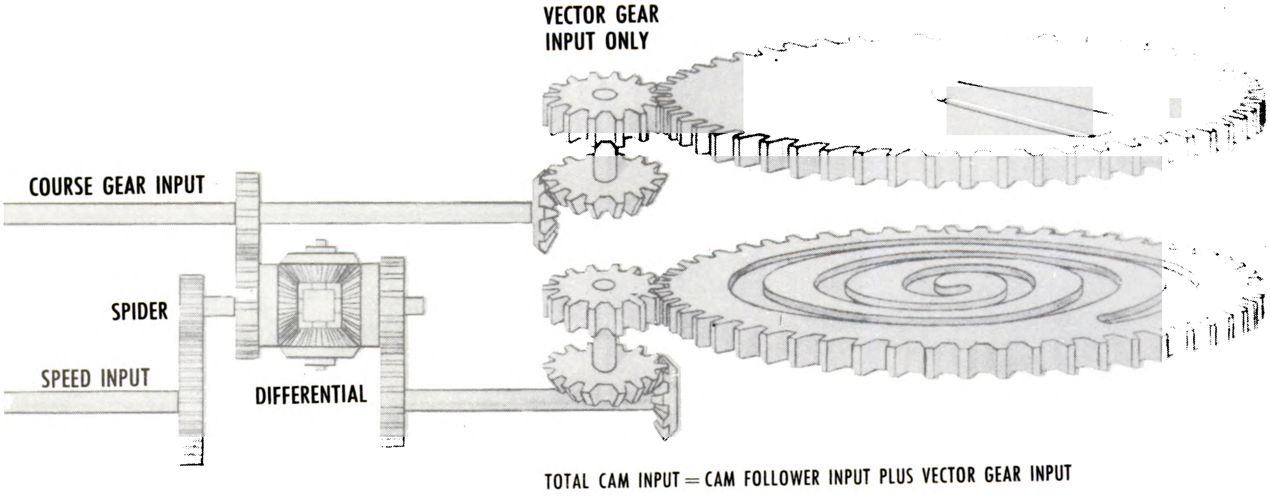


FIGURE 19E15.—Function of a compensating differential.

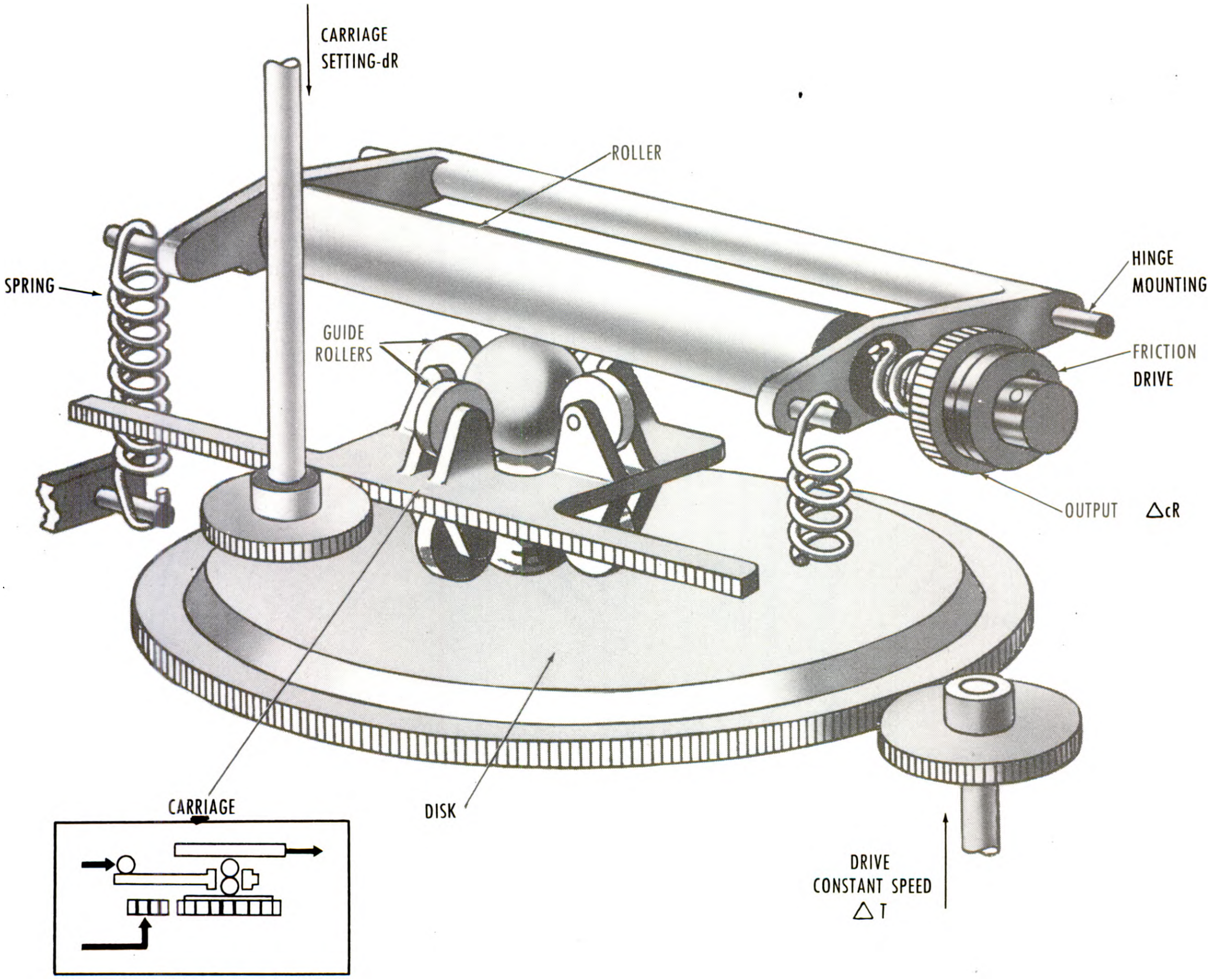


FIGURE 19E16.—The disc-type integrator.

driven by friction with the surface of the disc, and themselves driving an output roller; and suitable shafts and gears for transmission of values to and from the unit. Rotation of the disc rotates the lower ball, which turns the upper ball, and this in turn rotates the output roller. The balls are supported in a movable carriage so that the point of contact between the lower ball and the disc can be shifted along a diameter from the center of the disc to either edge. Spring tension on the roller provides sufficient pressure to prevent slipping. Two balls are used to reduce the sliding friction that results when only one is used.

The speed of roller rotation depends upon the speed at which the balls rotate. If the carriage is in the center of the disc, no motion is imparted to the roller. As the carriage is moved off center, the balls will begin to rotate, and will reach their maximum speed at the edge of the disc. The speed varies with the distance of the carriage from the center. Values of rotation on one side of center are considered positive, while if the carriage is moved to the opposite side, rotation will be in the opposite direction and will give negative output values.

Figure 19E17 illustrates a practical application of the integrator to the solution of the fire control problem. It shows a simple situation in which a target at constant speed traveling a straight-line course passes own ship, which is stationary. Although target speed remains constant, the component along the line of sight, which is the whole range rate in this case, will gradually change from a negative rate through zero to a positive rate. The *range rate* continues to change, although speed is constant. The integrator solves such a problem with ease. The constant speed of the disc represents time, and the position of the carriage is set to range rate. The output of the roller then is generated range increments (ΔcR) representing the sum of the products of time increments (ΔT) and range rate dR. These increments are added in a differential to the original setting of observed present range (jR) to give cR, generated present range.

19E9. Multipliers

In solving a fire control problem it is often necessary to multiply two continually changing values to produce a series of products. This is accomplished by a *multiplier*. Several types of multipliers are in use, all basing their solutions upon relationships existing between similar triangles. For reasons of space, it is convenient to build multipliers that deliver a fixed fraction of the answer, such as a tenth or a twelfth, rather than the complete numerical value required. The correct answer is supplied by suitable gearing.

Multipliers can take two continually changing input values and deliver an output that is proportional at every instant to the product of the two changing inputs.

The screw-type multiplier, illustrated in figure 19E18, has two inputs, which position a *slide* and a *rack*. The input slide is moved back and forth by two long-lead screws. The input rack is moved up and

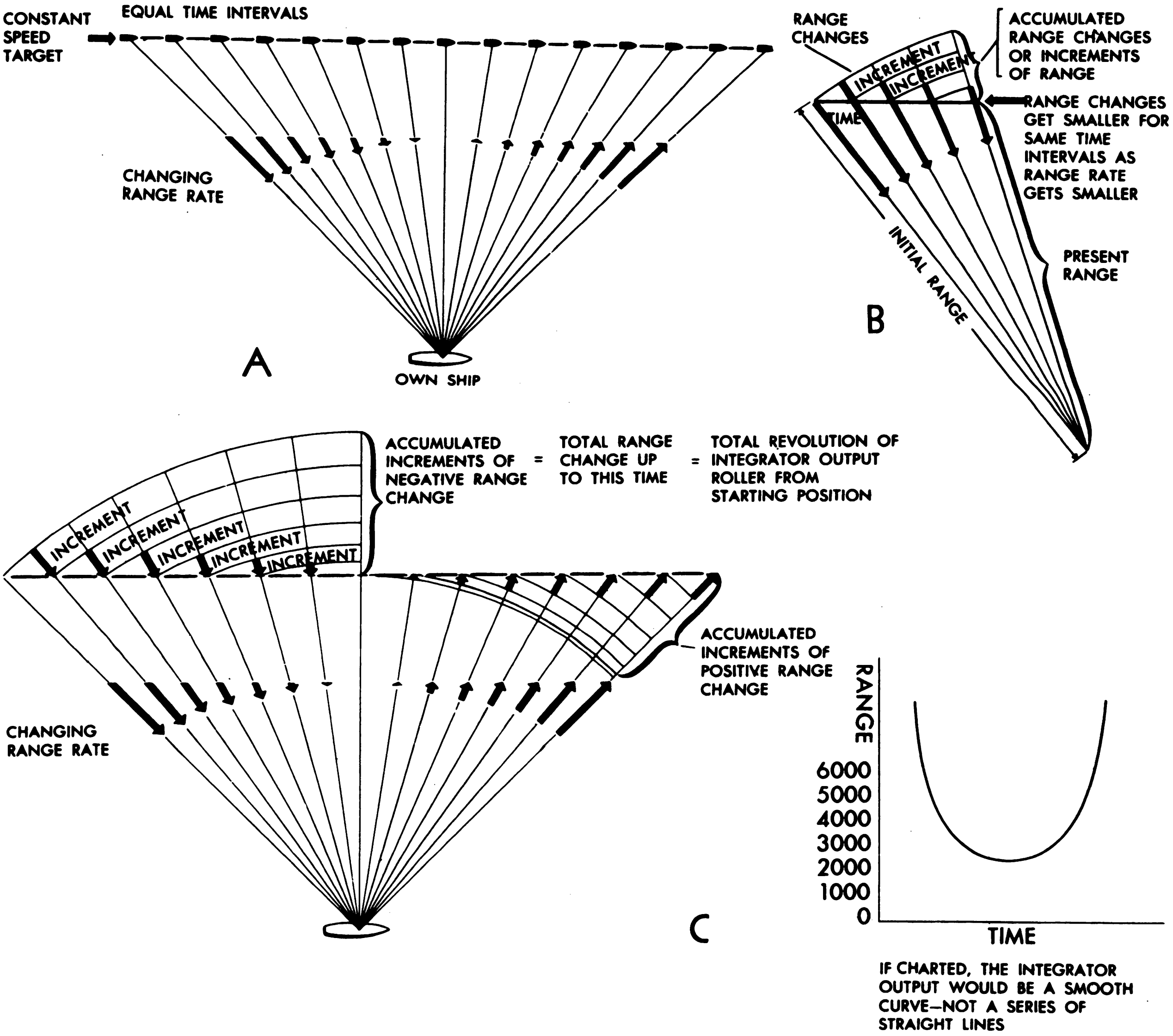

CONSTANT SPEED TARGET
EQUAL TIME INTERVALS
CHANGING RANGE RATE
A
OWN SHIP
RANGE CHANGES
ACCUMULATED RANGE CHANGES OR INCREMENTS OF RANGE
INCREMENT
INCREMENT
TIME
RANGE CHANGES GET SMALLER FOR SAME TIME INTERVALS AS RANGE RATE GETS SMALLER
INITIAL RANGE
PRESENT RANGE
B
ACCUMULATED INCREMENTS OF NEGATIVE RANGE CHANGE
=
TOTAL RANGE CHANGE UP TO THIS TIME
=
TOTAL REVOLUTION OF INTEGRATOR OUTPUT ROLLER FROM STARTING POSITION
INCREMENT
INCREMENT
INCREMENT
INCREMENT
INCREMENT
ACCUMULATED INCREMENTS OF POSITIVE RANGE CHANGE
CHANGING RANGE RATE
C
RANGE
6000
5000
4000
3000
2000
1000
0
TIME
IF CHARTED, THE INTEGRATOR OUTPUT WOULD BE A SMOOTH CURVE—NOT A SERIES OF STRAIGHT LINES

FIGURE 19E17.—Application of the integrator to the solution of the fire control problem.

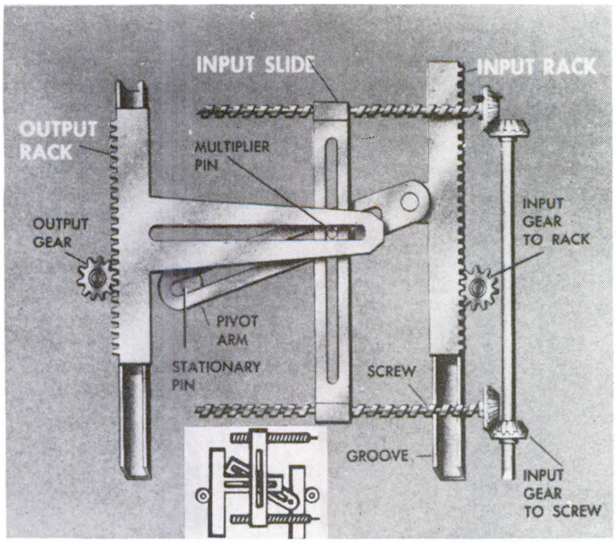


Figure 19E18.—Screw-type multiplier.

down by a spur gear. The input rack moves a slotted pivot arm that pivots around a stationary pin as the input rack is moved.

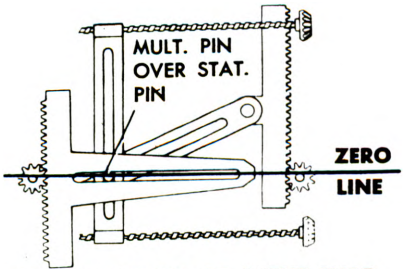
The *multiplier pin* is mounted in the slots of the input slide and the pivot arm where these slots cross. The position of this pin is changed by movement of the input slide or the input rack. The multiplier pin also fits into a slot in the *output rack*. As it changes position, the pin moves the output rack up or down.

The positions of the input slide and the input rack represent the two values to be multiplied together. The position of the output rack represents the output value, which is always proportional to the product of the two inputs.

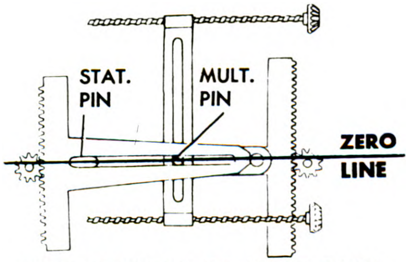
Suppose the lead screws are turned until the multiplier pin lies directly over the stationary pin. This is the zero position of the input slide, since, with the slide in this position, movement of the input rack will not produce any movement of the output rack. This is shown in figure 19E19.

Similarly, if the slot in the pivot arm is positioned parallel to the slot in the output rack, no amount of motion of the input slide can cause any vertical motion of the multiplier pin or of the output rack. This is the zero position of the input rack.

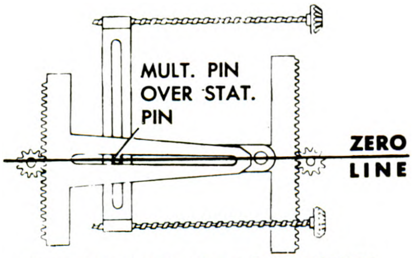
Starting with both inputs at their zero position, suppose both input gears turn a few revolutions in the directions indicated. The input slide will move to the right. The input rack will move up its groove, bringing the pivot arm into an angular position. The multiplier pin will be pushed to its new position by the combined action of the pivot arm and the slide. This pin will move the output rack, and the output rack will turn the output gear.



ZERO POSITION OF INPUT SLIDE



ZERO POSITION OF INPUT RACK



ZERO POSITION OF BOTH INPUTS

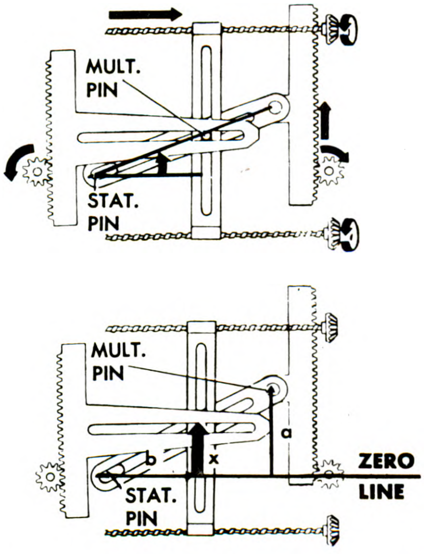


Figure 19E19.—How the multiplier works.

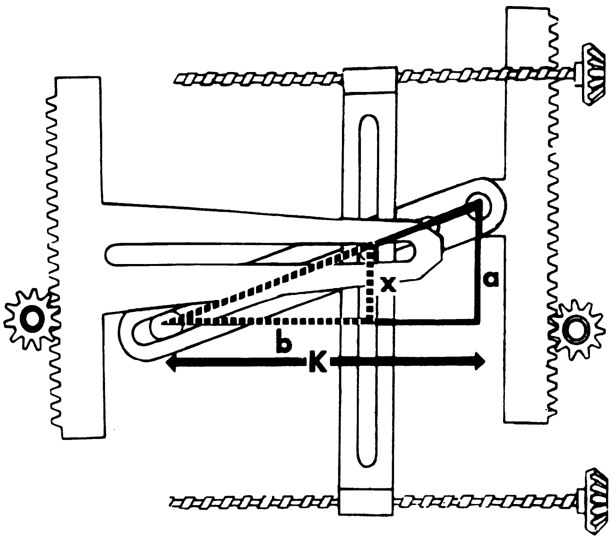


FIGURE 19E20.—Use of similar triangles in operation of the multiplier.

Now, labeling the distances each part has traveled from the zero line:

1. The input rack has moved up a.
2. The input slide has moved over b.
3. The output rack has moved up x.

If these distances are drawn on the diagram of the multiplier, they form two right triangles, as in figure 19E20. In the smaller triangle, the height, x, is the distance the output rack moved from zero. The base, b, is the distance the input slide moved from zero.

In the larger triangle, the height, a, is the distance the input rack moved from zero. The base K is the fixed distance along the zero line from the stationary pin to the pivot on the input rack. Note that the two triangles are similar. It can now be seen that the ratio between the height and the base of the smaller triangle is equal to the ratio between the height and the base of the larger triangle. That is: $\frac{x}{b}=\frac{a}{K}$ Multiplying both sides by b, $\frac{bx}{b}=\frac{ba}{K}$. Then, $x=\frac{ba}{K}$. This equation shows that the distance the output rack has moved from zero is equal to the product of the distances the input slide and rack have moved from zero, divided by a constant. In other words, the output is proportional to the product of the two inputs.

Since K is a fixed distance, it is a constant value in each multiplier. Its effect is removed by proper choice of input and output gearing.

Provision for both positive and negative x outputs can be made by placing the stationary pin at the center of the pivoted area.

F. Mechanical Solution—Basic Rangekeeper

19F1. General

The manner in which a computing instrument solves the surface fire control problem will be explained in this section, using the Rangekeeper Mark 8 as a model. This discussion is not to be considered a full presentation of the Rangekeeper Mark 8, which would be beyond the scope of this text; the student whose duties require more complete information is referred to the publications of the Bureau of Ordnance on the subject.

Figure 19F1 is a top view of the computing section of the Rangekeeper Mark 8, showing the arrangement of the various dial groups, knobs, and cranks. Figure 19F2 is a picture of the center dial groups, the upper dial indicating target course as well as wind direction; the lower dial showing own-ship course and target bearing. The line of sight from own ship to target is represented by the fixed indices, labeled "target bearing." The dials thus give a visual picture of the own-ship and target set-up (which is vectorially represented to the right of the dials on the figure).

To clarify discussion, the rangekeeper may be considered to have three fundamental sections. This is a functional division of the rangekeeper rather than a physical one. The sections are:

1. The tracking section.
2. The prediction section.
3. The correction section.

19F2. Tracking section

The tracking section, given proper inputs, continuously provides the rates of change of range and bearing due to motion of own ship and target. It also generates present range, cR, and relative target bearing, cBr. The target's actual position relative to own ship is determined continuously by the director, which measures range and bearing. The generated values of range and bearing developed in the tracking section established a continuous value of present target position. When the rangekeeper is receiving the correct inputs, the actual target position and the generated position should be the same; this can be checked by comparing the actual and generated values of range and bearing.

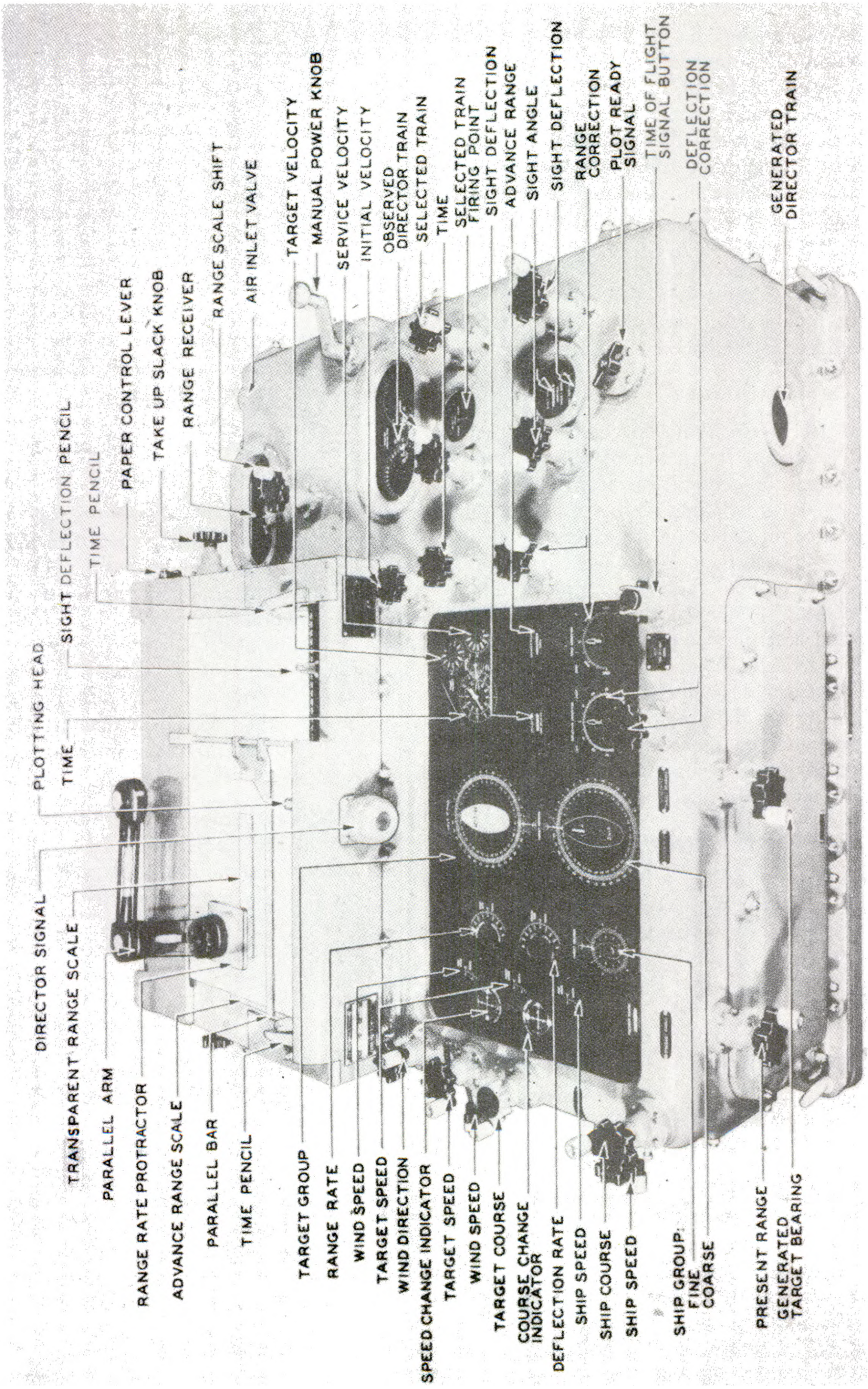


FIGURE 19F1.—Rangekeeper Mark 8.

19F3. Prediction section

Using values from the tracking section, the prediction section computes the position the target will occupy at the end of the time of flight. At the same time, this section computes the elevation and deflection offsets necessary to hit this predicted position in accordance with the range table and with existing variations from range-table standard conditions. The computation of these corrections is carried out in the ballistic part of the prediction section. The final step is to convert these predictions, including ballistics, into sight angle and sight deflection, the angular offsets from the line of sight which will position the gun to hit the target at the end of the time of flight.

19F4. Correction section

The correction section takes care of the effects of deck inclination. It has two parts, the *trunnion-tilt corrector* and the *deck-tilt corrector*. The trunnion-tilt corrector, as its name implies, corrects gun train and elevation for the tilting of the gun trunnions.

The deck-tilt corrector works out corrections to the line of sight to take care of deck inclination. The director measures the bearing of the target in the deck plane, but the computer works out its solution in the horizontal. Whenever the deck is tilted, these two values in the deck and horizontal planes will differ by the amount of the deck-tilt correction. The bearing in the horizontal plane is obtained by a differential which combines the bearing measured by the director with deck-tilt correction.

19F5. Rangekeeper computing mechanism

Having summarized in a few words the function of each major part of the rangekeeper, it will now be in order to return to each section of the instrument in turn for more detailed analysis. In the balance of this section of the chapter the intermediate quantities used in the development of gun orders will be considered as they are evolved from the original inputs to the computer. The ultimate purpose of the entire system is the computation of gun train order, *B'gr,* and gun elevation order *E'g,* the values which position the gun to hit the target.

19F6. Range rate, *dR*

The range rate, *dR,* is the algebraic sum of the components of own-ship and target motion in the line of sight: expressed in symobls, $dR = Yo + Yt$. The arrangement by which this is accomplished in the rangekeeper is shown in figure 19F3. Values of target angle, *A,* and target speed, *S,* (initially estimated by the spotter) are cranked into the target-component solver. The outputs of this component solver are the target components in and across the line of sight (*Yt* and *Xt* respectively).

Own ship's speed, *So,* which is received automatically from the pitometer log, is combined in the own-ship component solver with an input of relative target bearing. (The generated rather than observed value of target bearing is used, for reasons which will be explained later.) The resulting outputs are the own-ship components in and across the line of sight (*Yo* and *Xo* respectively). The components in the line of sight, *Yo* and *Yt,* are then added algebraically in a differential, as shown in the figure, to obtain range rate, *dR,* expressed in knots. This quantity is next changed from knots to yards per second by means of a simple gear ratio. The value of *dR* also, through appropriate gearing, positions a counter on the face of the rangekeeper, and is used by the operator to compare with measured range rate and thus determine if correct set-up of the elements has been made.

19F7. Increments of generated range, Δ*cR*

If some means is provided to multiply the rate of change of range by time as it elapses, the result will be a continuous set of increments of range in yards. A disc integrator, previously described, accomplishes this. The value of *dR* is used to position the carriage of the range integrator; the disc is revolved by a constant speed time motor. The resulting output of the integrator ($\Delta T \times dR$) is increments of generated range, Δ*cR,* which are constantly accumulated as shaft rotation.

19F8. Generated present range, *cR*

When the increments of generated range, Δ*cR* are added to the value of initial range, *jR,* as measured by the radar or rangefinder, the result will be generated present range, *cR*. Figure 19F3 shows how this is accomplished in the rangekeeper by means of a differential. The value of *cR* appears on a range counter on the face of the rangekeeper, except as noted in article 20E6 (4). It is also an important input to the prediction section.

19F9. Linear deflection rate, *RdBs*

Referring again to figure 19F3, it is seen that the deflection rate of the target, *Xt,* is an output of the target-component solver. The deflection rate of own ship, *Xo,* is provided by the own-ship component solver. These are added in a differential to produce the total linear deflection rate, *RdBs.* This is a linear rate in knots; it is then converted from knots to yards per second by means of a gear ratio.

19F10. Increments of bearing, Δ*cB*

It would be possible to compute linear increments of bearing in yards by multiplying *RdBs* by increments of

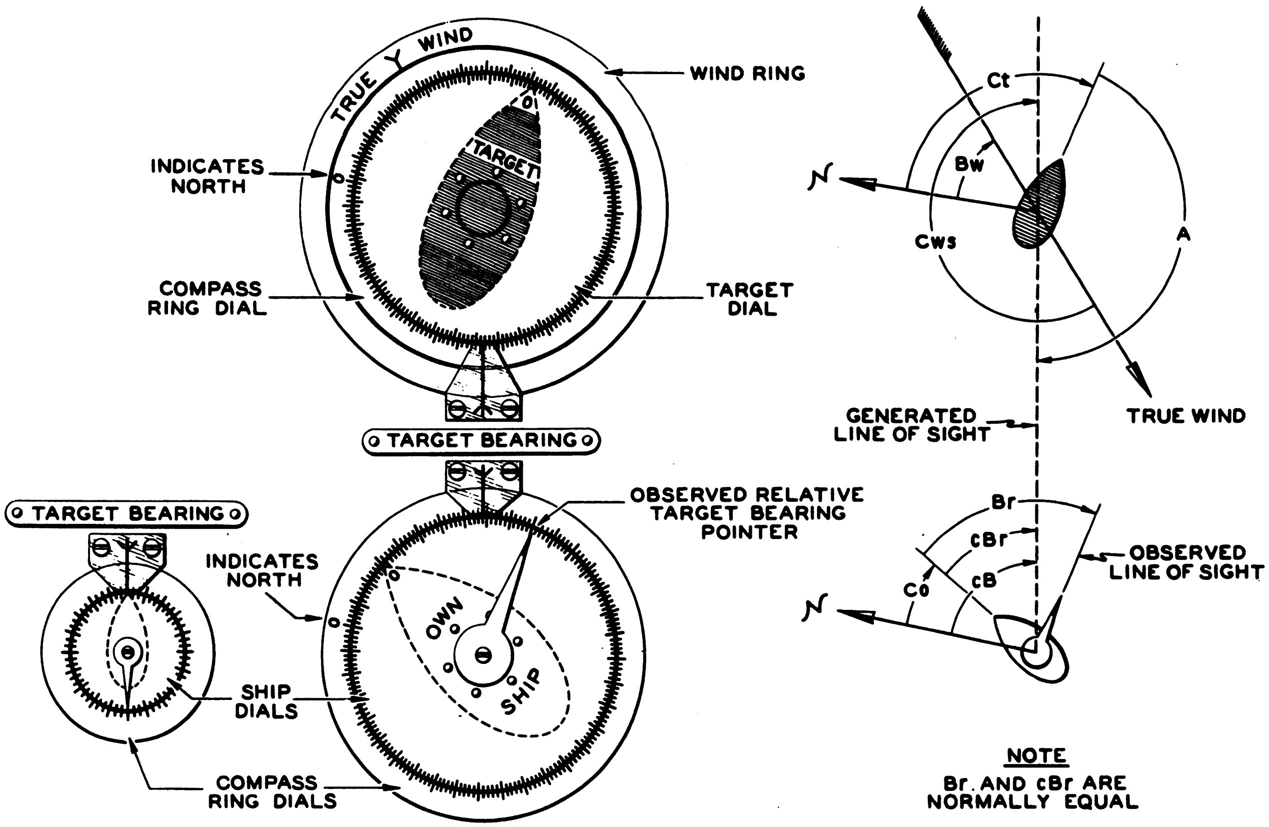


FIGURE 19F2.—Ship and target dial groups, Rangekeeper Mark 8.

elapsed time in an integrator, as was done in the case of increments of range. Since, however, an *angular* rather than a *linear* bearing rate is needed for the purpose of evolving generated bearing, it is necessary that a means be provided in the rangekeeper to convert linear increments of bearing, found as described above, to angular increments expressed in angular units, such as minutes of arc.

It should be noted (fig. 19F4) that $RdBs$ is measured at right angles to the line of sight; thus the value of $RdBs$ does not actually lie on the circumference of the imaginary circle drawn from own ship with range as the radius. A projection of the equivalent motion of own ship and target across the line of fire onto the circumference of an imaginary circle so described would be required for an absolutely accurate measurement of angular increments of bearing, ΔcB. The range is so great, however, that it is possible, without appreciable error, to consider that $RdBs$, although a straight line, does coincide with that small part of the circumference of the circle which is concerned. When this is done, a proportion may be set up as follows:

The linear change in bearing $RdBs \times T$ is to the linear circumference of the entire circle $2\pi cR$ as the angle ΔcB is to 360 degrees. The solution of the proportion in terms of ΔcB will then be (see fig. 19F4):

$$\Delta cB = 3{,}438 \times RdBs \times \frac{T}{cR}.$$

19F11. Mechanical solution of ΔcB

The mechanical units which solve the above formula $\Delta cB = 3{,}438 \times RdBs \times \frac{T}{cR}$, and which thereby generate increments of bearing, are shown schematically in figure 19F5. Present generated range, cR, from the units previously described (art. 19F8) drives a reciprocal cam. A groove is cut on the face of the cam disc so that the cam follower positions an output gear to represent the reciprocal of the input, $\frac{1}{cR}$, in this case. The value $\frac{1}{cR}$ then positions the carriage of an inverse range integrator, the disc of which is driven by the time motor at a constant speed representing time, T. The integrator multiplies the carriage input of $\frac{1}{cR}$ by time, T, continuously, and the output roller of the integrator turns at a speed proportional to the product

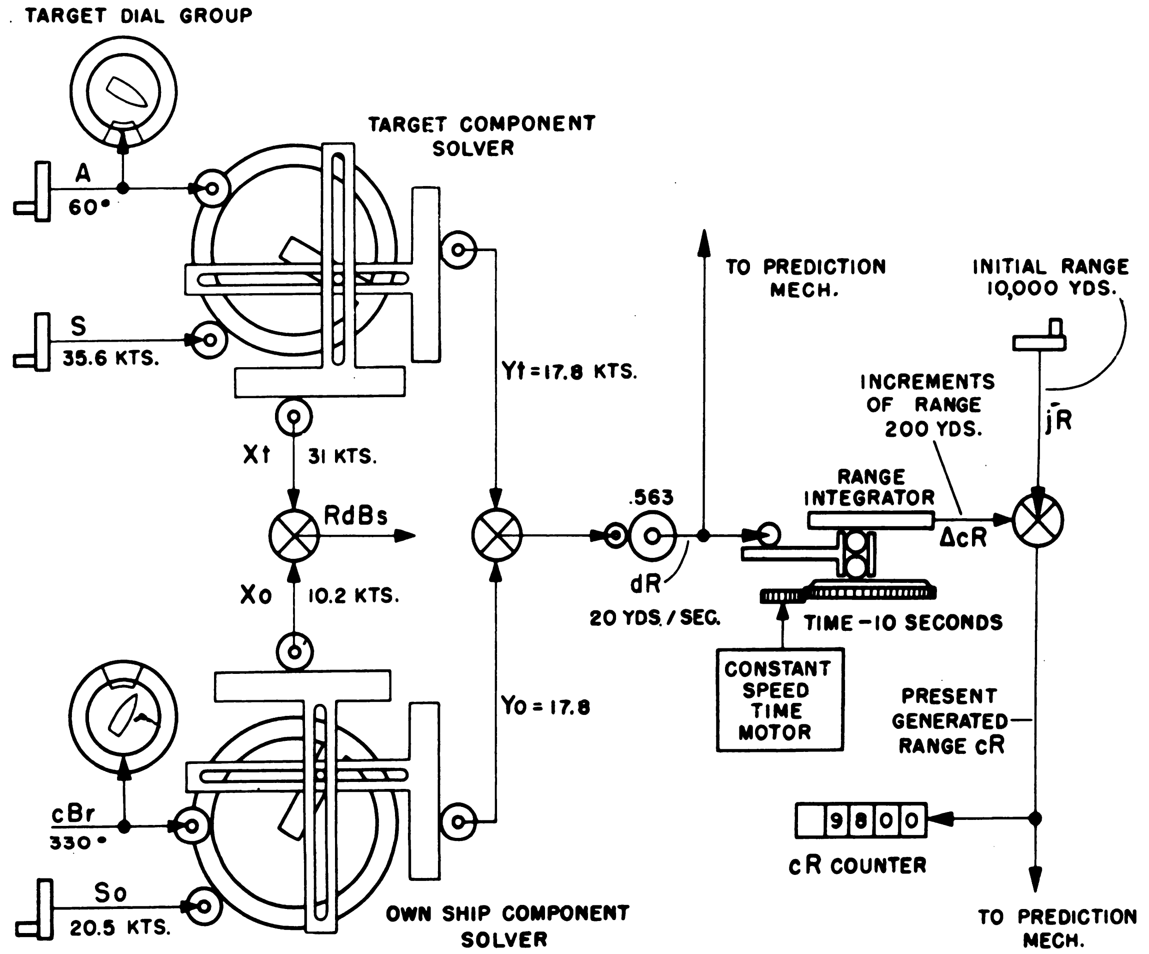


FIGURE 19F3.—Generation of present range.

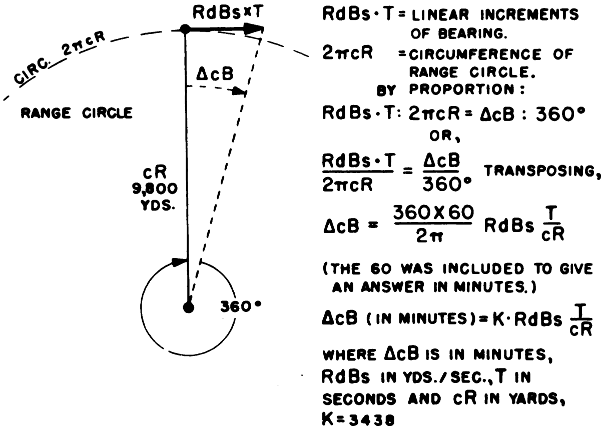

RdBs×T
CIRC. 2πcR
ΔcB
RANGE CIRCLE
cR 9,800 YDS.
360°
RdBs·T = LINEAR INCREMENTS OF BEARING.
2πcR = CIRCUMFERENCE OF RANGE CIRCLE.
BY PROPORTION:
RdBs·T : 2πcR = ΔcB : 360°
OR,
$\frac{RdBs \cdot T}{2\pi cR} = \frac{\Delta cB}{360°}$ TRANSPOSING,
$\Delta cB = \frac{360 \times 60}{2\pi} RdBs \frac{T}{cR}$
(THE 60 WAS INCLUDED TO GIVE AN ANSWER IN MINUTES.)
ΔcB (IN MINUTES) $= K \cdot RdBs \frac{T}{cR}$
WHERE ΔcB IS IN MINUTES, RdBs IN YDS./SEC., T IN SECONDS AND cR IN YARDS, K = 3438

FIGURE 19F4.—Derivation of formula for Δ*cB*.

$\frac{T}{cR}$. This output is then connected to the disc of a bearing integrator, as shown, the carriage of which is positioned by an input of *RdBs*. The output roller of the bearing integrator will now turn at a rate proportional to the product of $\frac{T}{cR}$ and *RdBs*. Introduction of the constant 3,438 by a suitable gear ratio (not shown in the figure) will produce the value $3{,}438 \times RdBs \times \frac{T}{cR}$ which equals ΔcB, increments of bearing in minutes of arc.

19F12. Generated relative target bearing and regeneration

Figure 19F6 shows in schematic form how those parts of the tracking section thus far described tie in and contribute to the over-all solution of the problem. It will also show how we obtain the value *cBr*. The value Δ*cB*, after leaving the bearing generating mechanism, is combined with initial bearing, *jB*, in a differential to produce target true bearing, *cB*. The increments of bearing drive through the differential unchanged, unless the *jB* crank is moved. It is also seen in the figure that *cB* combines with *Co* in another differential to produce generated relative target bearing *cBr*, which drives the own-ship component solver (and, as shown in fig. 19F2, to position the dials and and pointer of the own-ship group). In addition, *cB* combines with *Ct* in another differential, as shown, to produce target angle *A* (and, as shown in fig. 19F6, to position the target dial group). Thus, it is seen that a ***generated quantity***, Δ*cB*, is used to position the course gears of the own-ship and target-component solvers. This means that once the problem has been solved, this quantity, Δ*cB*, drives back continuously to reposition the component solvers in accordance with the development of the relative-motion problem. This process is called ***regeneration***, and is one of the most important features of the rangekeeper. Because of this regenerative feature, the rangekeeper is able to handle the indirect fire problem and, in fact, is able to continue to compute gun

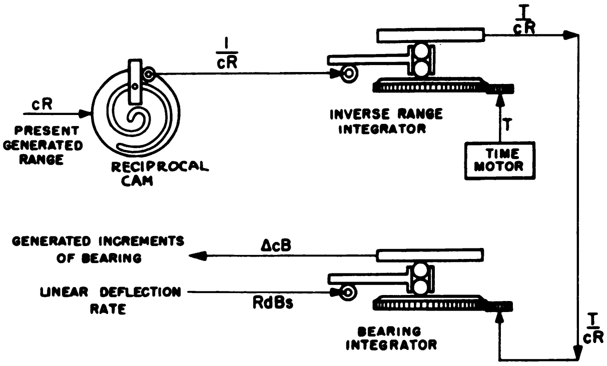


FIGURE 19F5.—Generation of bearing.

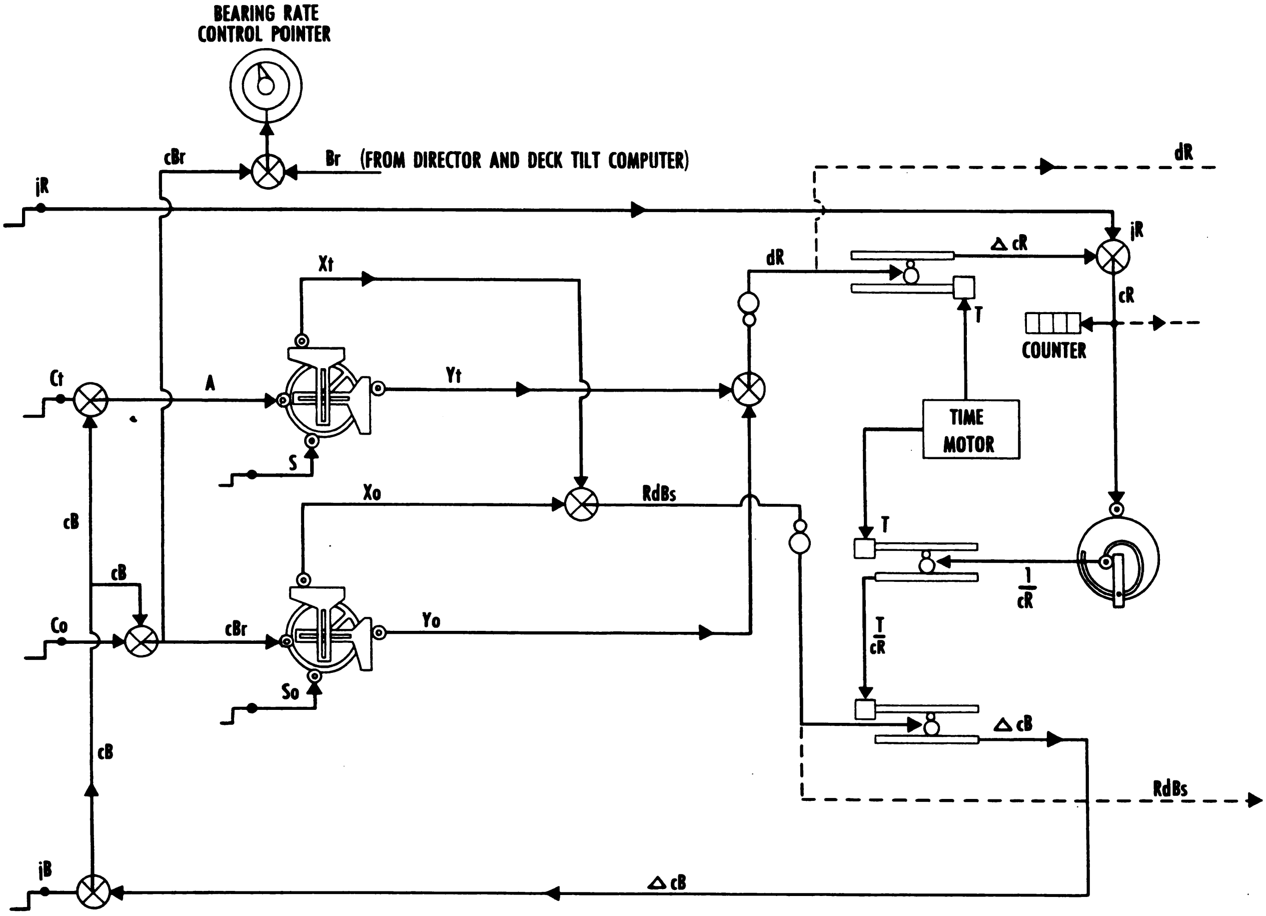


FIGURE 19F6.—Simplified schematic diagram of tracking section.

orders during any period when the director cannot see the target. Should the target change course or speed during such periods, of course inaccurate gun orders will result.

19F13. Summary of tracking section

The values supplied to the tracking section were (1) the known elements, *So* and *Co*; (2) the measured elements, *jR* and *jB*; and (3) the estimated elements, *A* and *S*. From these it has developed generated rates, *dR* and *RdBs*, and increments, ΔcR and ΔcB, which have been used to determine the generated quantities *cR* and *cB*. Comparison of these generated values with the observed values transmitted from the director provides the rangekeeper operators with a method of checking the solution; *i. e.*, of checking the estimates used for the values of *A* and *S*. This feature of operation, known as rate control, will be further developed in article 20E7 of the next chapter.

The outputs of the tracking section, *dR*, *cR*, and *RdBs*, become inputs to the prediction section, which makes use of them in the computation of sight angle and sight deflection.

19F14. Prediction of sight angle, *Vs*

Sight angle, as computed by the rangekeeper, includes the corrections for four quantities; namely, relative motion during time of flight, range wind, initial velocity loss, and a quantity known as range error due to deflection. Sight angle is computed in the vertical plane, and the assumption is made that the gun and target are in the same horizontal plane; that is, target elevation is assumed to be zero. Sight angle is merely the angular equivalent, in minutes of arc, of advance range in yards.

Advance range differs from the actual range to the advance position of the target by the ballistic corrections. To compensate for factors such as own-ship motion, target motion, wind, and variations in initial velocity, the gun must be elevated for a range equal to present range plus the algebraic sum of the several range compensations. During the time of flight, the target will travel to the computed point of fall shown, and the projectiles will hit. The formula for advance range is $R2 = cR + Rj + Rtwmx$.

Present range *cR*, was generated in the tracking section. *Rj*, range spot, is entered into the rangekeeper as sent down from the director. It is now necessary to consider the several elements comprising *Rtwmx* and show how each is computed in the prediction section of the rangekeeper. The prediction *Rtwmx* is the sum of the following elements:

1. *Rt*—the range prediction to compensate for relative target motion during the time of flight, *Tf*. Relative target motion includes own-ship motion. It will be recalled that own-ship's motion imparts additional velocity to the projectile, which is the effect here considered. Obviously any motion of own ship after the projectile leaves will have no effect on the projectile's travel.

2. *Rw*—the range prediction to compensate for the effect of apparent wind on the projectile.

3. *Rm*—the range prediction to compensate for variations from the designed initial velocity.

4. *Rx*—the range prediction to compensate for the effect of deflection exclusive of drift.

19F15. Range prediction, *Rtw*

The predictions to compensate for relative target motion and for wind are made in a multiplier called a range predictor (see fig. 19F7). If *dR*, the range rate, is multiplied by *Tf*, the result will be the relative motion in range during the time of flight. Since ownship and target motion are added together to form *dR*, wind due to own ship's motion must be handled separately. This is done by using ***apparent wind***, a fictitious value which combines vectorially the true range wind and the range wind due to own ship's motion. True-wind direction and velocity are set in the rangekeeper, the outputs of the wind-component solver being *Yw* and *Xw*, components of true-wind velocity in and across the LOS. Since apparent wind is the resultant of own-ship motion reversed and true-wind motion, range components of these elements are then combined in a differential, the output of which is *Ywr*, the component of apparent wind velocity along the line of sight ($Ywr = Yo + Yw$).

Instead of multiplying *dR* and *Ywr* by *Tf* separately, it is simpler to combine them and eliminate one multiplier. In computing *Rtw* ($Rt + Rw$), an empirical formula $Rtw = Tf\ (dR - KYwr) + K1Ywr$ must be used, since $Tf \times Ywr$ alone will not produce the change in range caused by range wind (Ywr).

Referring again to figure 19F7, it is seen that range rate *dR* and apparent range wind *Ywr* are combined in a differential to give $dR - KYwr$, and this output is then multiplied by *Tf* to give *jRtw*, to which $K1Ywr$ is added in a differential to give *Rtw*, the range prediction due to relative target motion and apparent range wind during the time of flight.

19F16. Range correction for I. V. loss and deflection exclusive of drift, *Rmx*

Referring to the schematic diagram of the prediction section, figure 19F10, it can be seen that *Rtw*, computed above, goes into a differential. Into the other side goes *Rmx*, the quantity now to be considered.

The correction *Rm* is easily understood, as it takes care of changes in the initial velocity due to erosion or other causes. The setting is made by the initial-velocity knob and dial, which introduces *jRm* as shown in figure 19F9.

The need for correction *Rx* is not so apparent and can best be shown by a simplified example. In figure 19F8, own ship is shown to be motionless and the target is moving to the right from position 1 at the instant of firing to position 2 at the end of the time flight. At position 1 target angle is assumed to be 90°; range rate therefore is zero. It is also assumed for simplicity that there is no wind blowing and that the projectile leaves the guns at the design value of initial velocity.

Since *dR* is zero when the target is at position 1, the range prediction (*Rt*) will also equal zero and the value of advance range will be equal to present range. With the guns elevated for present range and deflected to compensate for the target's rightward motion during the time of flight, it is obvious from the diagram that the salvo will fall short by the amount *Rx*.

This error is the result of computing the range prediction from an instantaneous value of *dR* which is based on the present line of sight; whereas *dR* will actually be a changing value if *Br* and *A* are changing during the time of flight. It will be noted that drift is excluded in the computation of *Rx*. The reason for this is that when the data for the various range tables are collected at the proving grounds, the range error caused by drift is compensated for. For instance, when a test round is fired at a gun elevation of 20°, the range to the point of fall is actually measured, and any loss of range due to drift is thus taken care of in the range-table values.

From figure 19F9, it can be seen that drift, *Df*, is subtracted from total sight deflection, *Ds*, leaving *Dtwj*; that is, deflection exclusive of drift, and empirically *jRx* equals $K\ (Dtwj)^2$. *jRx* is added to *jRm* to give *jRmx*, which is one input to the range-correction multiplier, the other input being *R2*. The output is *Rmx*.

19F17. Total range correction, *Rjtwmx*

As shown in the schematic, figure 19F10, range prediction *Rtw*, is now combined with range correction,

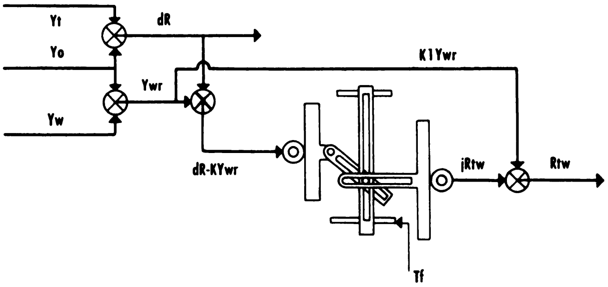


FIGURE 19F7.—Range predictor.

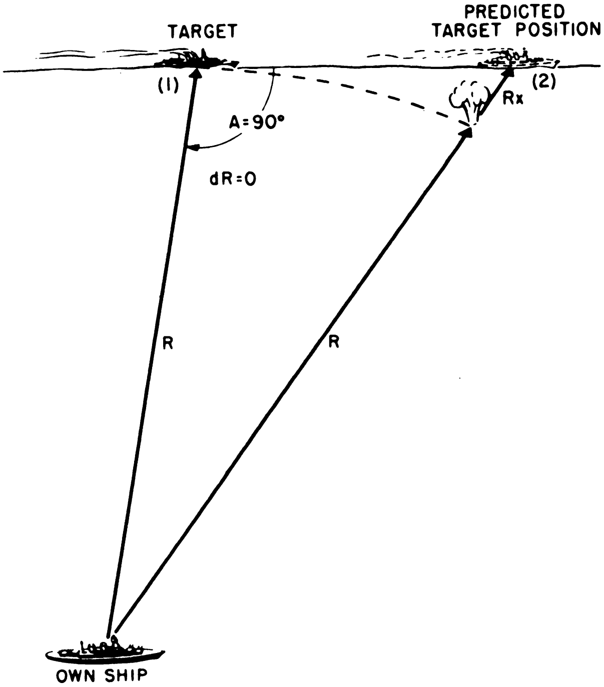


FIGURE 19F8.—Why range correction for deflection is necessary.

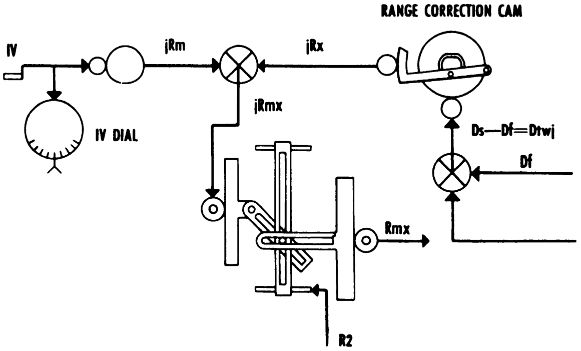


FIGURE 19F9.—Range-correction multiplier.

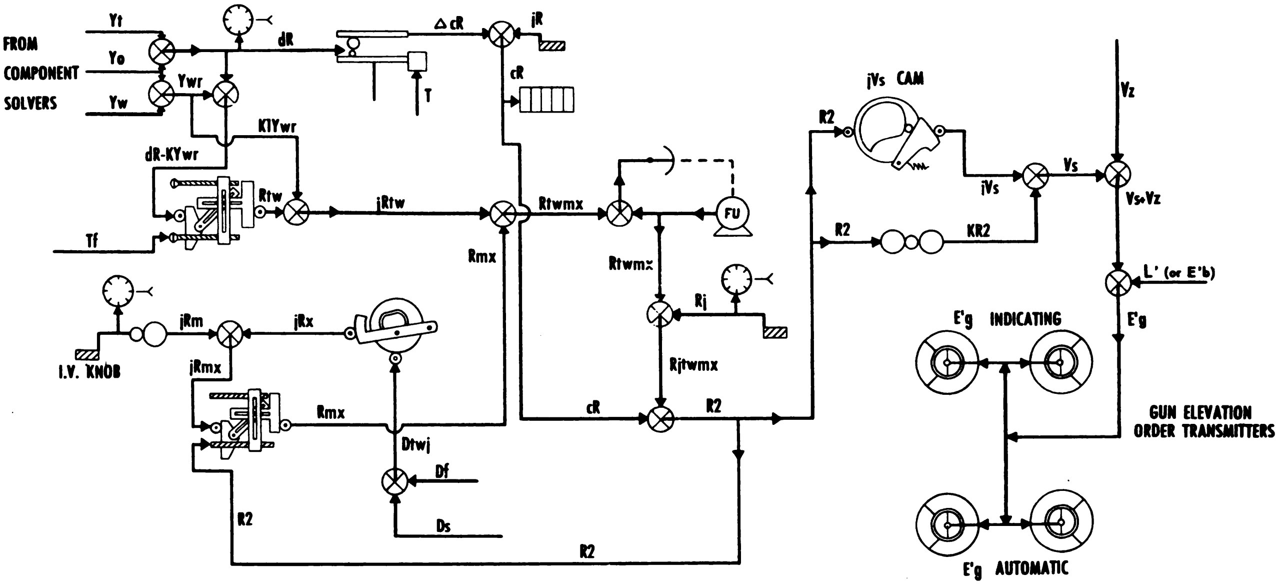


FIGURE 19F10.—Generation of range, elevation prediction, and gun elevation order, Rangekeeper Mark 8.

Rmx, in a differential to give $Rtwmx$. Range spot, Rj, if any, is then combined with $Rtwmx$ in another differential, the output of which is total range correction, $Rjtwmx$.

19F18. Advance range, $R2$

From the schematic, figure 19F10, it can be seen that advance range, $R2$, is obtained by adding the total range correction, $Rjtwmx$, to the present generated range, cR, driven in from the tracking section. It should be recalled that advance range, $R2$, is not equal to the actual range to the target's predicted position, the difference being due to the ballistic corrections for I. V. loss, range correction due to deflection, wind, and range spots. These corrections are included to ensure that the gun will be elevated the proper amount to hit the predicted position. If not included, the effects mentioned above would cause the projectile to fall short of or over the predicted position. Although $R2$ is a fictitious value and not the actual range to the target's predicted position, when this range is converted into sight angle and applied at the guns, the result should be a gun elevation which will cause hits on the target.

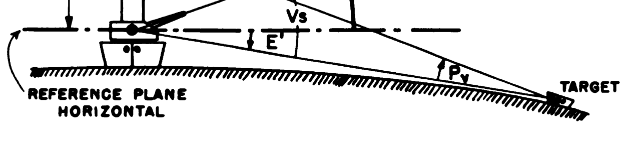


FIGURE 19F11.—Gun elevation order with deck horizontal.

As shown in the schematic, $R2$ is used for several purposes in the prediction section. The most important use is its conversion by means of a cam into its equivalent angular value, sight angle Vs, which is used in making up gun elevation order and for setting the sights at the guns. $R2$ is also a necessary input to the range-correction mechanism. Other uses of $R2$ in the deflection part of the prediction section (namely as inputs to the wind-deflection multiplier, the $\frac{Tf}{R2}$ cam, and the drift, Df, cam) will be discussed as they are encountered.

Also, $R2$ furnishes another good example of regeneration. It can be seen from an inspection of figure 19F10 that $R2$ is used to compute and correct itself; for example, it is used to compute Rmx, which became part of $R2$.

19F19. Sight angle, Vs

As mentioned above, $R2$ is used to compute sight angle Vs. Inspection of any range table will show that column 1 tabulates range in yards, while column 2 shows the corresponding sight angle. In the ballistic computer there are two sets of cams, one set for firing armor-piercing projectiles at full and at reduced velocities, and the other for firing high-capacity projectiles at full and at reduced velocities. Both sets are designed to function in accordance with this range-table relation. As shown on the schematic, $R2$ rotates the $V's$ cam and computes $jV's$, a partial correction, while $R2$ in a gear train computes $KR2$, the straight-line function. When combined in a differential, $jV's+KR2=V's$. This value is now ready to be used in making up gun-elevation order.

19F20. Prediction of sight deflection

The next step to be considered is the computation of sight deflection, *Ds*, the angular amount which the bore of the gun must be offset in the horizontal plane from the LOS. This quantity is made up of the following elements:

1. *Dt*—deflection prediction to compensate for relative target motion in deflection during the time of flight.
2. *Dw*—deflection prediction to compensate for the effect of apparent wind on the projectile during the time of flight.
3. *Df*—deflection prediction to compensate for drift.
4. *Dj*—manual deflection correction (spots).

19F21. Deflection prediction for relative motion, *Dt*

We have already studied the computation of *RdBs*, linear deflection rate due to relative motion of own ship and target, also the computation of advance range $R2$, and of Tf corresponding to advance range. If *RdBs* and Tf are multiplied, the result will be the linear deflection (in knots, which can be converted to yards per second by a gear ratio) due to own-ship and target motion. As has been stated, it is easier to visualize this motion if own ship is considered stationary and the combined motion of own ship and target are represented as target motion, as is done in figure 19F12. When $RdBs\times Tf$ is known, the predicted position of the target at end of Tf is determined. However, to direct the guns, angular deflection from the LOS, *Dt*, is needed. In order to convert from linear to angular measure, advance range $R2$ must be considered, because the angular prediction varies with range and becomes larger as range decreases. The formula employed is similar to that described in connection with generation of increments of bearing. The formula is:

$$Dt=3{,}438\times RdBs\times\frac{Tf}{R2};\text{ in which}$$

Dt is in minutes,
RdBs is in yards per second,
Tf is in seconds, and
R2 is in yards.

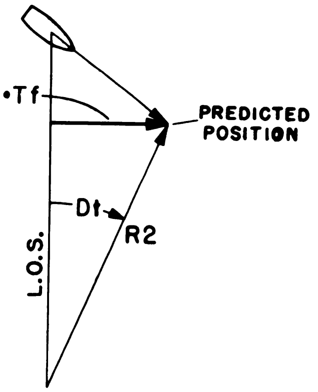


FIGURE 19F12.—Deflection correction for relative target motion.

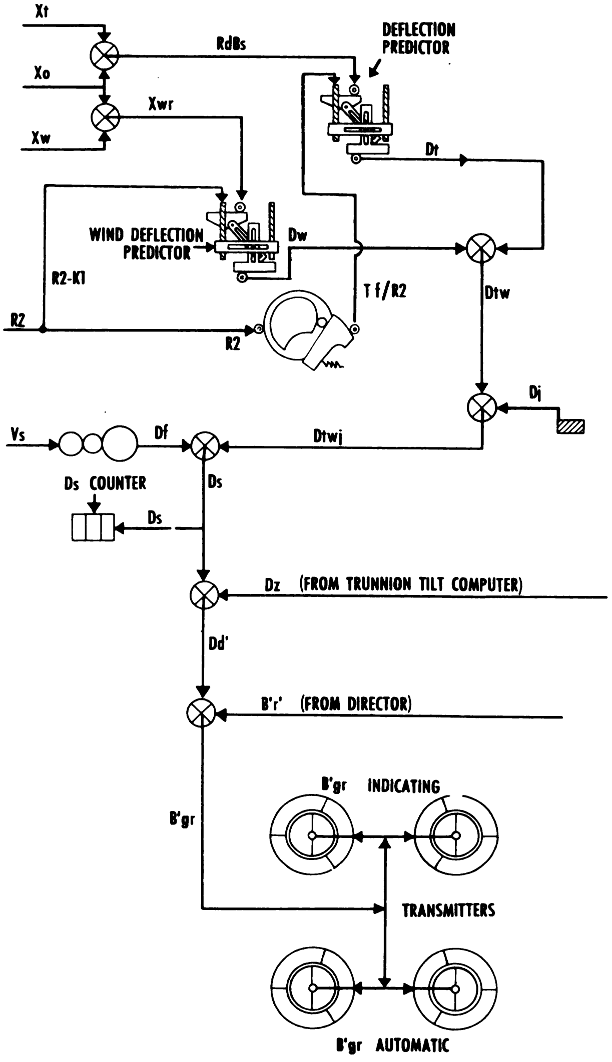


FIGURE 19F13.—Generation of deflection predictions and gun train order.

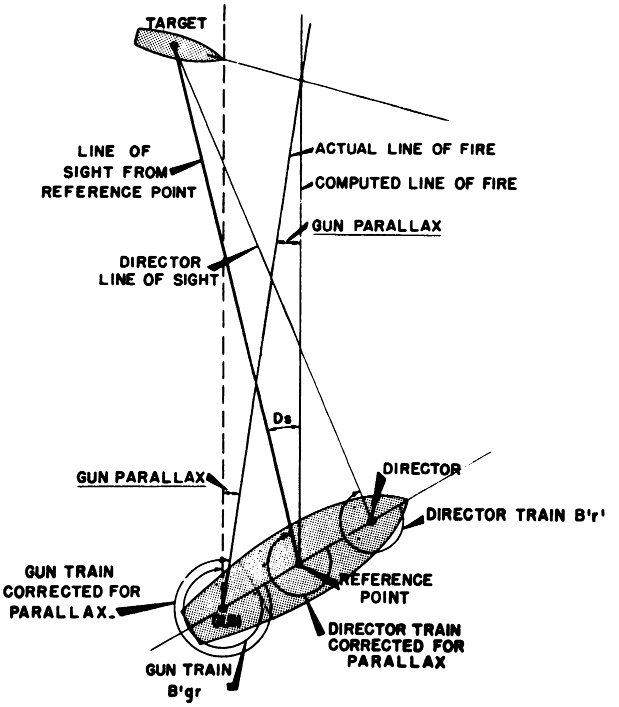


FIGURE 19F14.—Gun train order with deck horizontal.

Reference to the schematic, figure 19F13, shows how the rangekeeper solves the above formula mechanically. The linear deflection rate *RdBs*, from the tracking action, is multiplied by $\frac{Tf}{R2}$ in the deflection-prediction multiplier to produce *Dt*. The constant *K* (3,438) is introduced by a gear ratio (not shown). After establishment of *Dt*, the angular prediction for relative motion, corrections must be made for wind and drift.

19F22. Correction for wind, Dw

Deflection prediction to compensate for the effect of apparent wind on the projectile, *Dw*, is computed in a multiplier known as the wind-deflection predictor. *Xo* (reversed) and *Xw* are added algebraically in a differential to give *Xwr*, the component of apparent wind velocity across the line of sight. This is multiplied by *R*2 to give *Dw*. Actually an empirical formula is used; $Dw=(R2-K1)\ Xwr$.

The quantities *Dw* and *Dt* enter a differential to produce *Dtw*, as shown on the schematic. Deflection spot, *Dj*, if any, is applied by hand crank to make *Dtwj*. It will be recalled that *Dtwj* is used in the range correction mechanism to compute *Rx*, the range correction for deflection exclusive of drift.

19F23. Correction for drift, Df

The angular correction for drift increases as range increases; and, since this correction *Df* is very nearly proportional to advance range *R*2, *Df* is shown in the schematic, figure 19F13, as being produced by a gear ratio from an input of sight angle *Vs*. $Df=(K-K1)\,Vs$.

NOTE: Actually drift, *Df*, and *Tf* vary with *R*2 and are nearly proportional to *Vs*. In the rangekeeper the sight-angle cam output, *Vs*, after passing through suitable gearing, is used for *Df* and $\frac{Tf}{R2}$.

Df is added to *Dtwj* in a differential to produce sight deflection *Ds;* this value is now ready to be used in the computation of gun-train order.

19F24. Summary of prediction section

The inputs to the prediction section were *dR, cR, RdBs, Xwr,* and *Ywr* from the tracking section as described above, and a manual input of I. V. loss. In addition the prediction section receives any range and deflection spots which may have been made. The resultant outputs are *Ds* and *Vs;* these quantities are sent to the gun mounts for the purpose of setting the gun sights.

If it were not for the roll and pitch of the ship, gun orders could be made up simply by adding the computed values of sight angle and sight deflection to director elevation and director train, as shown in figures 19F11 and 19F14, thus:

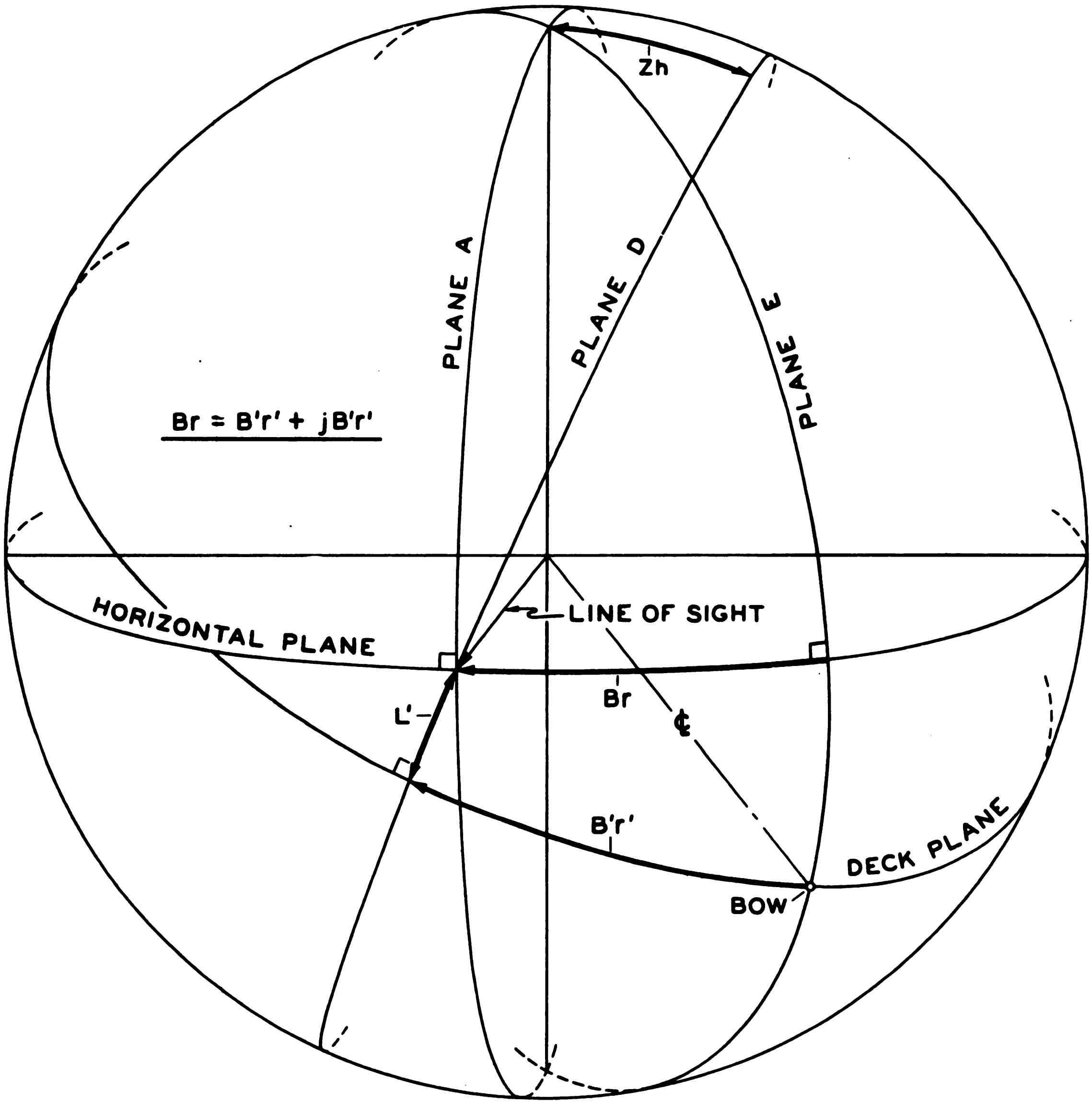
$$E'g=E'b+Vs.$$
$$B'gr=B'r'+Ds.$$

It will be noted that these formulas not only assume a level deck, but also disregard corrections for parallax and roller-path inclination. This is justified by the fact that, in surface systems, the necessary corrections for these errors are made in instruments located at the directors and gun mounts, rather than in the rangekeeper.

Since the deck plane is rarely level, *Vs* and *Ds,* in addition to being used in computation of gun orders, must also be sent as inputs to the correction section, where with other values they form the basis of the correction necessitated by the inclination of the deck.

19F25. Level and crosslevel

Before considering in any detail how the two correctors in the correction section function, it is advisable to learn some of the details of the manner in which level and crosslevel are measured. Refer to figure 19F15. Level angle, *L'*, is measured about an axis in the deck; it is the angle between the horizontal plane and the deck plane, measured in the plane perpendicular to the deck through the line of sight. (This



PLANE A - VERTICAL PLANE CONTAINING LINE OF SIGHT

PLANE D - PLANE PERPENDICULAR TO DECK PLANE CONTAINING LINE OF SIGHT

PLANE E - VERTICAL PLANE THROUGH CENTERLINE OF SHIP

FIGURE 19F15.—Spherical diagram of deck-tilt correction.

definition applies to level angle, *L'*, as measured in main-battery systems of battleships and cruisers which use the Rangekeeper Mark 8. It does not apply to level angle, *L*, as used in the Computer Mark 1 for certain dual-purpose battery installations.)

As shown in figure 19F15, the line of sight is considered to be in the horizontal. Except for extremely short range, this assumption introduces no error (see art. 17A6). The deck plane is shown tilted with respect to the horizontal in such a direction that both level and crosslevel angles exist. By the definition of level angle (*L'*) above, *L'* is measured in plane D—the plane perpendicular to the deck plane containing the line of sight—and it is the angle between the deck plane and the horizontal measured about an axis in the deck normal to plane D.

Crosslevel, Zh, is measured about the axis in the horizontal plane where the horizontal plane and the vertical plane containing the line of sight intersect; it is the angle between the vertical plane (plane A) and a plane perpendicular to the deck (plane D) through the axis just defined above.

19F26. The trunnion-tilt corrector

The trunnion-tilt corrector is installed in the Rangekeeper Mark 8 for the purpose of computing corrections to gun elevation order and to gun train order caused by the depression of one trunnion below the other. Referring to article 19B12, it will be recalled that, when the trunnion axis leaves the horizontal, the gun will elevate in a plane other than the vertical, and that the effective elevation above the horizontal will be less than Vs. A deflection error is also introduced, the effects of which are generally more serious than the elevation error. The trunnion-tilt corrector provides the necessary elevation correction Vz, and the train correction Dz, which are used in the rangekeeper as shown in figure 19F16.

The Stable Vertical Mark 41, which supplies the values L' and Zh, will be taken up in the next section. The trunnion-tilt corrector computes Dz and Vz by solving the formulas:

$$Dz=[Zh+K1L'\cdot Ds]\cdot[f(L')f_1(Vs)+KVs].$$
$$Vz=K2(Zh^2\cdot Vs-K3Zh\cdot Ds.$$

These formulas are given merely to show the values entering into solution of Vz and Dz. They will not be further developed in this text, nor is it necessary to remember them.

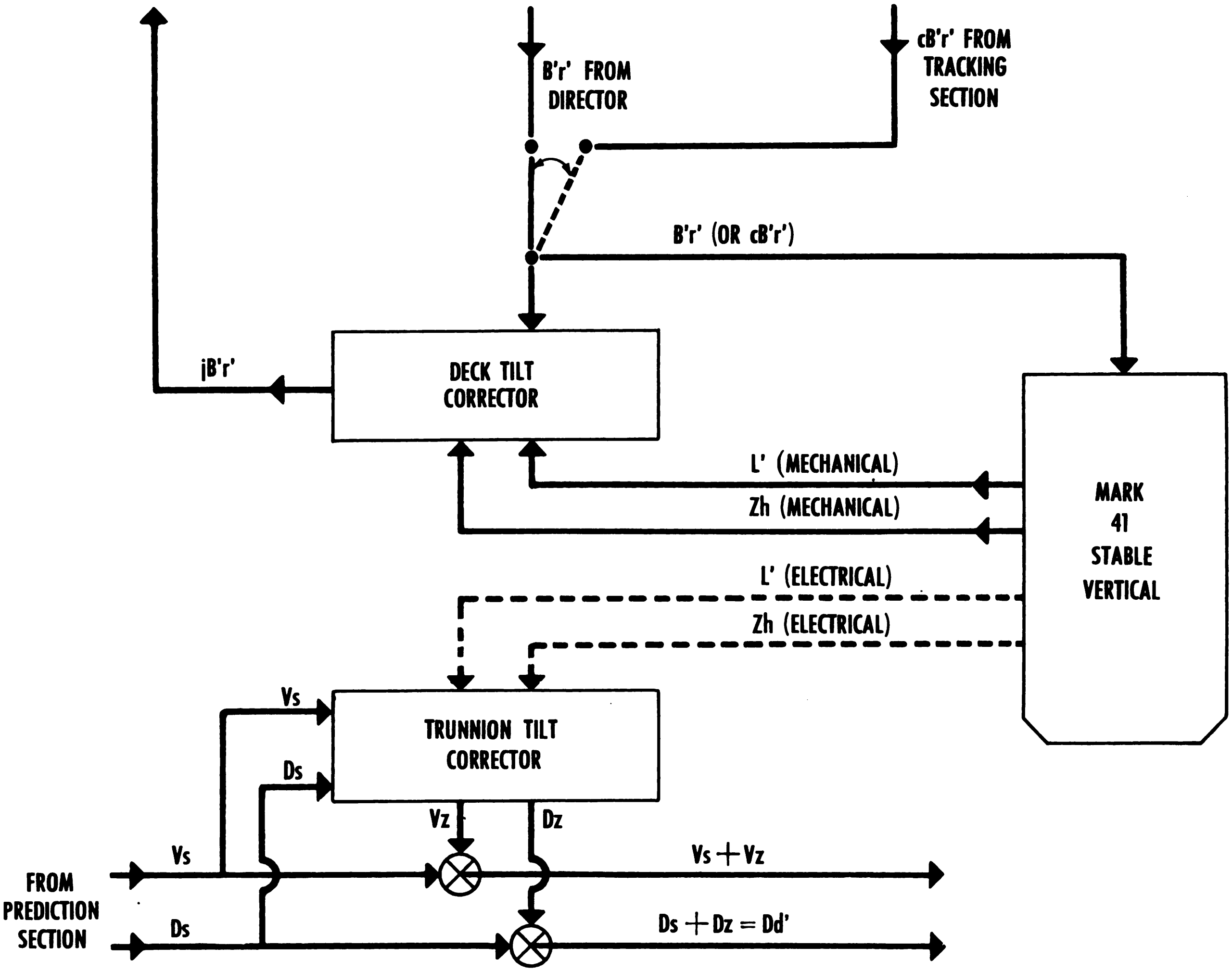


FIGURE 19F16.—Simplified diagram of correction section.

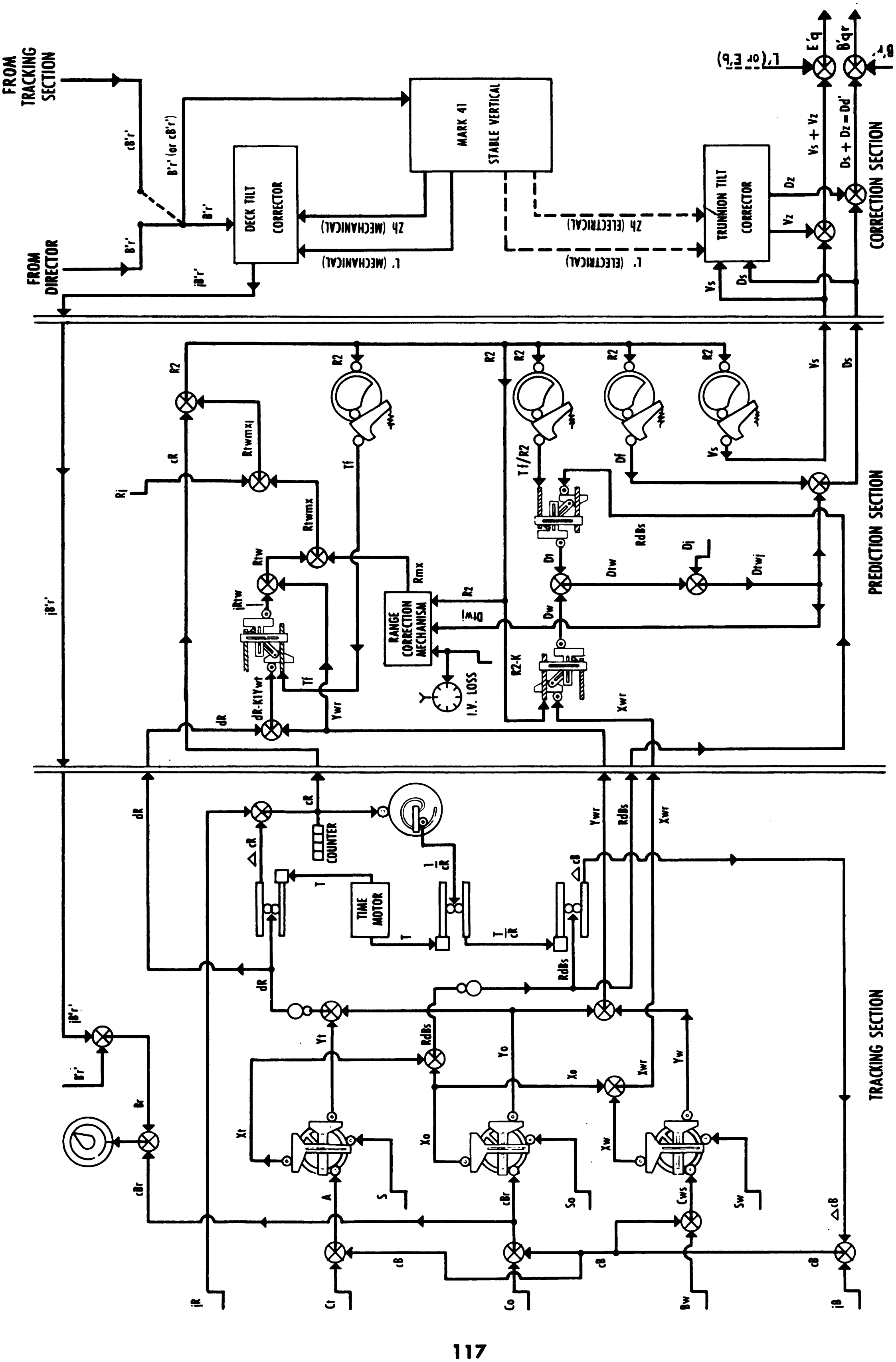


FIGURE 19F17.—Simplified schematic diagram of basic rangekeeper.

19F27. Deck-tilt corrector

The function of the deck-tilt corrector is to correct *B′r′*, as measured in the deck plane, to a corresponding value of *Br* measured in the horizontal. Observed director train as received from a director must of necessity be measured in the plane of the director's roller path, which is assumed here to be parallel to the reference plane. In order to compare generated target bearing, *cBr*, which is measured in the horizontal plane, with observed director train, *B′r′*, a correction, *jB′r′*, is added to the latter to convert it to bearing in the horizontal plane as shown in figure 19F16, thus changing it into observed target bearing, *Br*, in the horizontal plane. The correction, called deck-tilt correction *jB′r′*, is the output of the deck-tilt corrector, which solves the formula:

$$jB'r' = K\{ \tfrac{1}{2}\ [(L')^2 - (Zh)^2] \sin 2B'r' - L'Zh\,[1 + \cos 2B'r']\}$$

Again, the formula need not be memorized, and it is given to show the student that the deck-tilt corrector requires inputs of *B′r′*, *L′*, and *Zh*.

19F28. Summary of correction section

The inputs to the correction section are *Vs* and *Ds* from the prediction section, and *cB′r′* from the tracking section (the last used in place of *B′r′* in the full regenerative set-up). *B′r′* is received from the director; *L′* and *Zh* are received from the stable vertical.

The output to the tracking section is *jB′r′*, which is therein combined with *B′r′* to produce *Br*.

The other outputs of this section are $(Vs+Vz)$ and *Dd′* which equals $(Ds+Dz)$. These quantities can now be used to compute gun orders which will be accurate with the deck tilted. The formulas given in paragraph 19F24, when modified to obtain corrections for tilt, are as follows.

$$E'g = E'b + Vs + Vz.$$
$$B'gr = B'r' + Dd'.$$

These expressions assume that the elements of the system are aligned to the reference plane, and that there is no parallax. Corrections for roller-path tilt and parallax are discussed in the next two articles, which summarize all quantities making up gun orders.

19F29. Gun elevation order

Gun elevation order is based on the elevation of the director pointer's line of sight to the target, and is made up as shown in figure 19F18. This situation represents the most general case; that is, one which includes the most variables.

The director, when the sight is kept on the target, measures director elevation, *E′b*, which, with the deck inclined in level, includes level *L′*. *E′b* is corrected for vertical parallax and for director roller-path tilt to form the first element of gun elevation order, target position relative to the reference plane, measured from a reference point at the height of the gun.

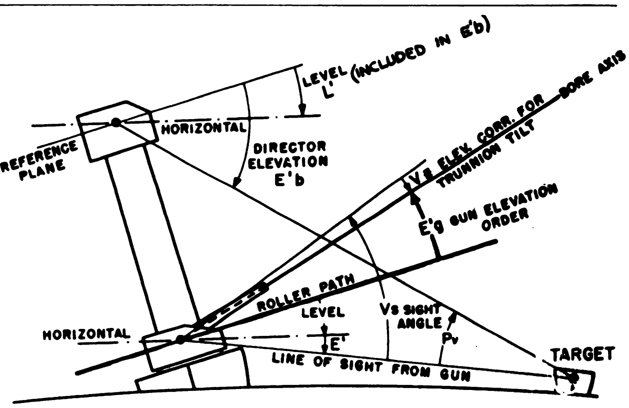


Figure 19F18.—Gun elevation order with deck inclined.

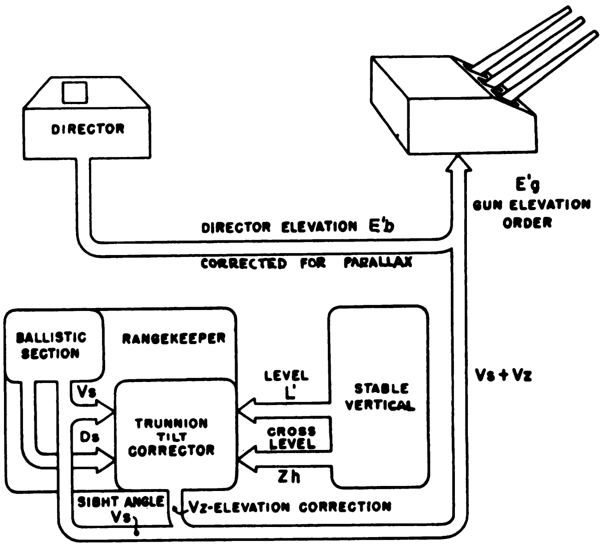


Figure 19F19.—Gun elevation order, the system.

Assuming for the moment that the gun roller path is parallel to the reference plane, all angles at the gun may be measured from the gun roller path, which represents zero gun elevation. Referring to figure 19F18, it can be seen that the angle level (*L′*) in effect reestablishes the horizontal plane. Measured below this is the angle *E′*, target elevation from the horizontal, which establishes a line of sight to the target from the reference point at the gun. Of course, the angles *L′* and *E′* do not exist separately in the mechanism; they are transmitted together in the form of director elevation *E′b* (*i. e.*, $E'+L'$) corrected for vertical parallax.

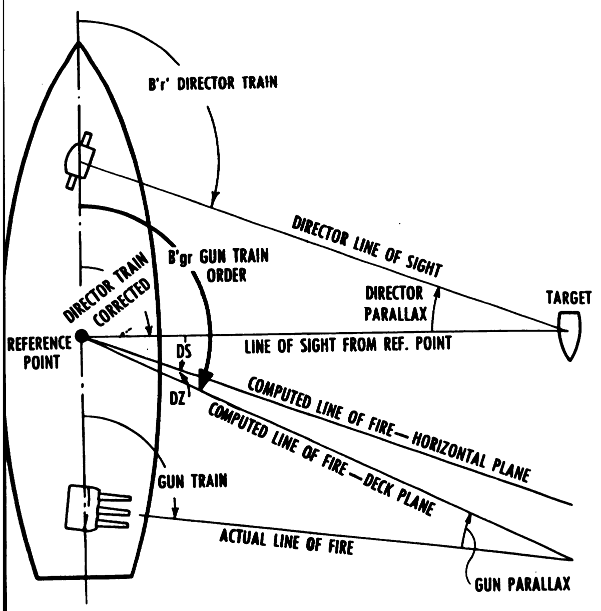


FIGURE 19F20.—Gun train order with deck inclined.

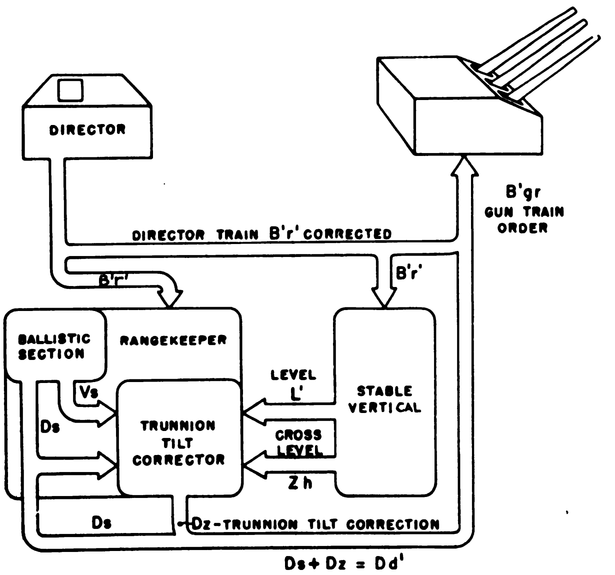


FIGURE 19F21.—Gun train order, the system.

This value, $E'b$, is the first basic element, present position of the target relative to the deck.

At this point the gun has received a signal which, when laid off from its roller path, gives a line of sight to the target. Now, if sight angle Vs is added to this signal, it can be seen in the figure that a gun position above the line of sight to account for predictions and ballistics is established. As has been previously mentioned, although Vs is computed to produce a hit on a target in the same horizontal plane as the gun, a slight depression E' below that plane will not create a measurable error, in accordance with the principle of rigidity of trajectory.

The gun-bore position above the line of sight must be corrected for trunnion tilt by the value Vz. The total angle of the bore axis above the roller path is gun elevation order, $E'g$. Since the roller path may not actually lie in the reference plane, the roller-path tilt corrector at the gun makes the necessary correction for this discrepancy. Figure 19F18 shows $E'g$ as a composite angle, measured from the gun roller path, and made up of each of the corrections discussed above.

Figure 19F19 is a diagram of the director, rangekeeper, stable vertical, and guns, in which the origin of the various quantities is shown. These quantities are actually combined *within* the rangekeeper, but they have been shown outside for clarity.

19F30. Gun train order

Gun train order is shown diagrammatically in figure 19F20. Director train, $B'r'$ establishes the target position relative to ship's centerline, measured in the deck plane. A non-reference director will include a horizontal parallax corrector, which will cause the director to transmit director train corrected for parallax, which in effect establishes a line of sight from the reference point, as in figure 19F20. This gives present position of the target relative to ship's centerline and in the deck plane.

Measured from the fictitious line of sight from the reference point, sight deflection, Ds, is applied to account for predictions and ballistics, as can be seen in figure 19F20. Ds is computed in the horizontal plane, but if crosslevel is present the trunnion-tilt train correction, Dz, is added to produce the computed line of fire from the reference point. The sum of these angles is the angle that the computed line of fire makes with own ship's centerline; that is, gun-train order, $B'gr$, in the deck plane. Gun train order is transmitted to the guns, where the proper horizontal parallax correction is applied to produce actual gun train to hit the target. Having reviewed the elements of gun train order, it remains to review how they originate in the system.

Figure 19F21 is a diagram of the gun train system. Although gun train order is actually made up *within* the rangekeeper, certain basic quantities are shown combined outside for clarity. As shown in figure 19F21, director train, $B'r'$, corrected for horizontal parallax, is received by the rangekeeper. It also is transmitted to the stable vertical to keep the gimbals oriented with the line of sight, so that the stable vertical can measure the values of level and crosslevel in the proper planes. Director train, *B'r'*, establishes present position of the target, measured from own ship's centerline in the deck plane.

The prediction section computes sight deflection, *Ds*, in the horizontal plane, to account for relative motion and deflection ballistics.

The train correction, *Dz*, for trunnion tilt is computed in the trunnion-tilt corrector. This value accounts for the effect of crosslevel on the gun bore. *Dz* is added to *Ds* to produce deck deflection, *Dd'*, and this in turn is added to *B'r'* to produce gun train order, *B'gr*, in the deck plane, which is then corrected for horizontal parallax at each gun.

G. Mechanical Solution—Establishing the Horizontal Plane

19G1. Introduction

Guns are installed with their roller paths parallel to the deck plane, so that their movement is limited to train in the deck plane and elevation above the deck plane. On the other hand, *Vs* and *Ds* are computed with reference to the horizontal. Since the deck plane of a moving ship deviates from the horizontal by the amount of roll and pitch, some means must be found to measure and correct for this discrepancy. Correction for deck inclination is most satisfactorily applied in the solution of the fire control problem if it is resolved into components in planes in and across the line of sight. The component in the line of sights, called *level,* then becomes a modification to elevation; while the component across the line of sight, called *crosslevel,* affects both train and elevation, as it causes the trunnions of the guns to tilt.

In early director systems the pointer's telescope established the line of sight and a crosslevel telescope at right angles to it was kept on the horizon. The amount these telescopes had to be elevated or depressed from their zero position measured the tilt of the deck, and was applied as a correction within the rangekeeper. This method is used as a standby procedure in one modern system. It is fairly satisfactory, but is subject to human error, and is useless when the horizon is not visible.

Modern surface systems use, as their primary method of measuring level and crosslevel, an instrument called a *stable vertical,* which is essentially a gyroscope equipped with suitable mechanical and electrical pick-offs. This instrument establishes and maintains the true vertical and its associated horizontal plane, continuously measures level and crosslevel, and transmits these values mechanically and electrically to the Mark 8 rangekeeper.

19G2. Gyroscopic principles

To understand the action of the stable vertical, it is necessary to understand the principles of the gyroscope. Any rapidly spinning mass will show the characteristic properties of a gyroscope. But for simplicity this discussion will be confined to a wheel, spinning rapidly on its axis.

A rapidly spinning wheel shows two properties that make it especially useful in fire control instruments. One of these properties is *rigidity in space.* This means simply that a wheel, as long as it is spinning rapidly, tends to keep its axis pointed in the same direction *in space.* (Because the earth itself is spinning, the wheel will not necessarily tend to keep its axis pointed in the same direction with respect to the earth's surface. This is explained in article 19G4.)

A spinning top shows a good example of gyroscopic action. When it spins at high speed, the top remains erect, keeping its axis vertical. As the speed dies down, the axis is no longer able to maintain a fixed direction in space; the top begins to wobble, and eventually falls over. A bicycle wheel is another familiar example. Because of gryoscopic action, a bicycle is more easily balanced at high speed than when it is moving slowly.

Another name for the principle of "rigidity in space" is *gyroscopic inertia.* The inertia of the spinning wheel is the cause of its gyroscopic action. To understand this, consider the effect of inertia on any point on the wheel's rim. The law of inertia states that when any body is in motion, it will continue indefinitely to move in a straight line, at the same speed, unless acted on by some external force. Any point on spinning wheel is moving in a circular path. Because of its inertia, such a point will tend to move in a straight line, tangent to its circular path. But molecular attraction within the wheel tends to hold the particles together, and at normal speeds will confine all particles in the wheel to circular paths. (However, any wheel will fly apart if it is spun with sufficient speed.) The inertia of all the particles in the wheel, then, will tend to keep these particles moving in circular paths, with the result that the wheel tends to keep spinning in a single plane, and its axis tends to point in a single direction. The wheel will maintain its plane of rotation, and the axis will maintain its fixed direction, until the system is acted on by some outside force.

The inertia of a spinning wheel, and therefore the reliability of its gyroscopic action, depends on two things: the mass of the wheel, and the speed with which it is moving. For that reason, a gyroscope is relatively heavy, and is rotated at high speed. The speed of any particle on the gyroscope wheel depends not only on the speed of rotation, but also on the distance of the particle from the center. For that reason the weight of a gyroscope wheel is usually concentrated in its rim.

Another useful property of a gyroscope is *precession.* This term refers to the manner in which a gyroscope responds to any force that tends to change its plane of rotation, or the direction of its axis. When the speed of a spinning top decreases, gravity tends to pull the top down, and turn its axis horizontal. The top responds to the force of gravity by moving its axis *at a right angle* to the applied force. The resulting wobble is an example of precession.

Another example may be seen when a high-speed electric fan is turned about a vertical axis. The resulting precession tends forcibly to turn the fan at a right angle to the applied force, moving the blades toward a *horizontal* plane. (Unless the blades are well enclosed, this is a dangerous experiment.)

A study of figure 19G1 will show that precession, like rigidity in space, is a result of inertia. Imagine that the larger wheel in the figure is spinning rapidly, in a direction shown by the arrow on its rim. If a force is applied that tends to move the wheel in its plane of rotation, or along its axis, no precession will result, since such forces do not tend to change the direction of this axis. But consider a force that tends to change the direction of the axis. Such a force is represented by the two arrows, marked "applied force." If the wheel were not spinning, this force would turn the wheel about the axis Y–Y. However, since the wheel is spinning rapidly, it responds to the applied force by precessing—by moving its axis in a direction at 90° from that of the applied force.

To understand this action, consider the forces acting on the point marked "A," at the instant represented by figure 19G1. The inertia of this moving point tends to carry it in the direction AC. The applied force tends to move point A in the direction AB. Assume that in the diagram the lengths of these two lines, AC and AB, are proportional to the respective magnitudes of the two forces. Since the point A can not move in two directions at once, it must respond to the two forces acting on it by moving in the direction AD. The direction and length of the line AD represents the direction and magnitude of the resultant (*vector sum*) of the two forces acting on point A.

Obviously, point A can move in the direction AD only by turning the wheel's plane of rotation to the position shown in the smaller diagram of figure 19G1.

So far, the discussion has been confined to the action of the single point A. A further study of the diagram, however, will make it apparent that at any given instant, every point on the wheel (with the exception of points on the axis Y–Y) will be acted on by two separate forces. In every case, the vector sum of these two forces is such as to turn the plane of rotation in the direction shown in the smaller diagram.

Precession, then, results in a movement of the axis in a direction at 90° from that of the applied force. As a result of precession, the axis of rotation (X–X), tends to become parallel to the axis of torque (Y–Y). Precession will continue until the applied force is removed. Inspection of figure 19G2 will provide a ready means of determining direction of precession. If a downward force is exerted on the gyro case as shown (at north) a gyro rotating clockwise will precess in the direction indicated (to the east).

Since level and crosslevel are angles measured between the reference plane and the true horizontal, the stable vertical accomplishes this measurement by containing a free gyro mounted inside an instrument case. The case itself is bolted to the deck in such a way as to be exactly parallel to the reference plane. Then, with the gyro maintaining its spin in the horizontal, the differences between the position of the gyro and the reference plane are measured and applied as needed.

19G3. Righting system

The gyro wheel is made to assume a horizontal position while spinning, and to maintain its original plane of rotation, by means of a *mercury control system* which opposes any external force tending to displace it.

Essentially the mercury control system consists of two tanks containing mercury, attached to the casing which houses the gyro wheel, on diametrically opposite sides of the wheel. These two tanks are joined by a narrow connecting tube, so that mercury is free to flow from one tank to the other. As long as the gyro wheel is exactly horizontal, the mercury level in both tanks will be the same; but as soon as the wheel is tilted from the horizontal by some external force, gravity will cause mercury to flow from the high tank to the low tank. The additional mercury in the low tank will then produce the same effect as a downward pressure exerted at the low point of the gyro wheel. Application of the rule of precession (fig. 19G2) shows that this will only cause the wheel to precess more out of the horizontal in a direction 90° away. However, if the mercury effect is applied not at the low point but 90° from the low point, pressure at this point causes

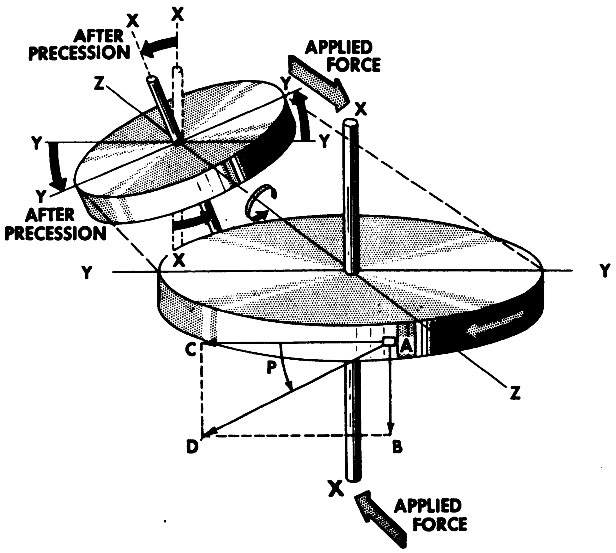


Figure 19G1.—Gyro principle.

the low point of the gyro to precess upward to its original horizontal position, at which point the mercury is redistributed equally. This effect is accomplished in the stable vertical by rotating the entire gyro assembly and attached mercury tanks at 18 rpm in the same direction as gyro spin, and by restricting the size of the orifice to regulate the flow of mercury in the connecting tube. The net result is that by the time the mercury has reached the low tank, the low tank has been displaced 90° from the low point of the gyro wheel, and the pressure exerted here causes the gyro spin axis to precess back into the vertical.

It should now be apparent that when the gyro is first started, exactly the same action takes place to cause the gyro spin axis automatically to erect itself and settle in the vertical, after several minutes of operation.

19G4. Effect of the earth's rotation

Further consideration will indicate that the horizontal plane necessary for purposes of fire control is a plane tangent to the earth's surface at the ship's position. A gyroscope originally set in this plane will not remain in the horizontal, as the earth rotates, unless some means is provided to compensate for the effect of earth's rotation.

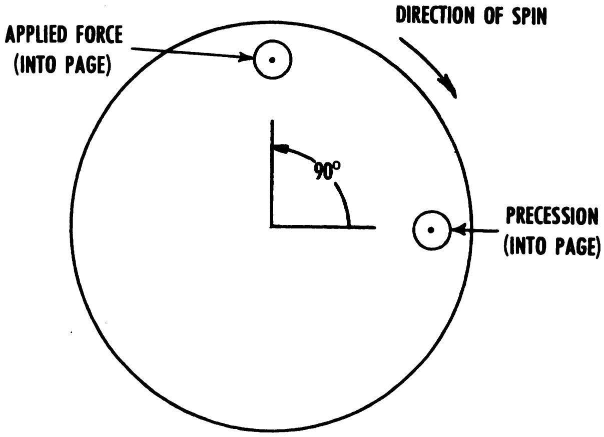


Figure 19G2.—Precession diagram.

A gyro located at either pole will be unaffected, as the plane tangent to the earth at these points remains

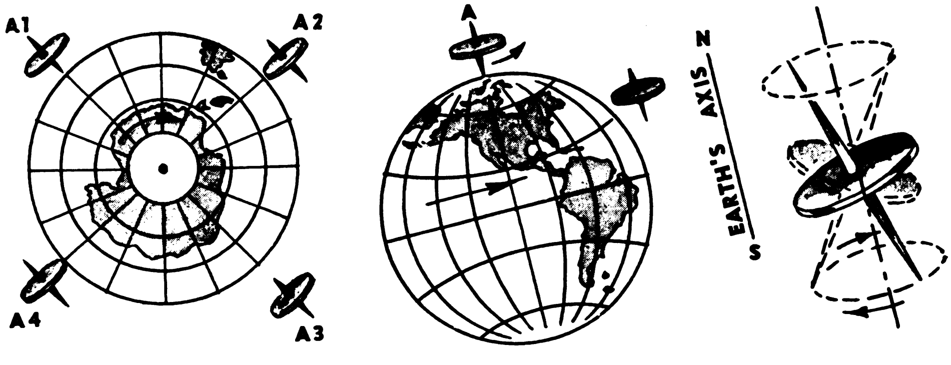


Figure 19G3.—Effect of earth's rotation on relative position of gyro.

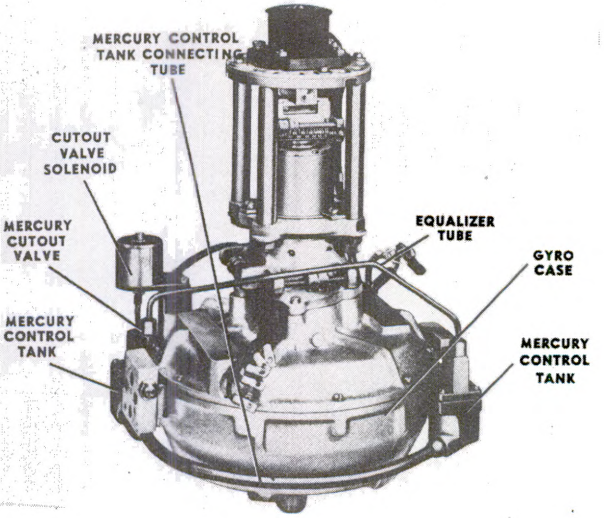


FIGURE 19G4.—Gyro assembly.

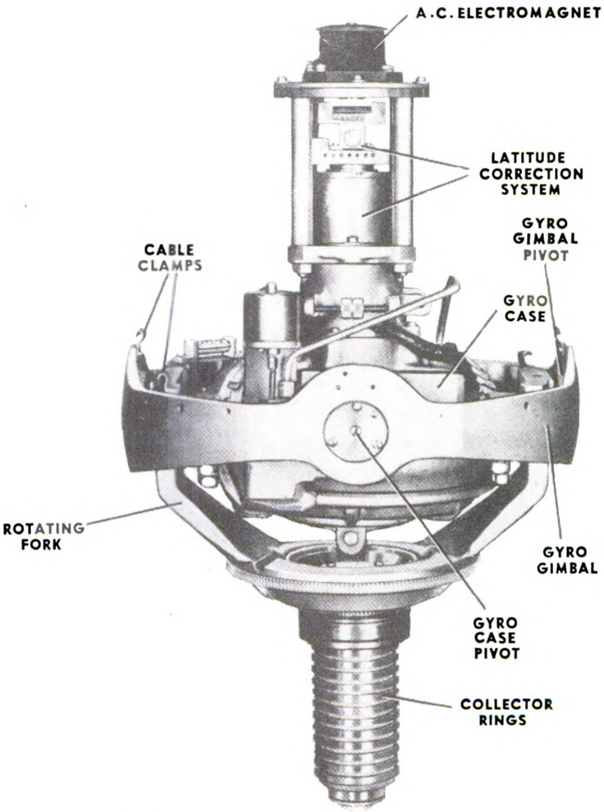


FIGURE 19G5.—Gyro assembly installed in gyro gimbals.

fixed in space. On the other hand, a gyro located at the equator will assume the successive positions with respect to the earth shown in figure 19G3 (A). To an observer standing on the earth, the wheel will appear to turn completely over every 12 hours; that is, turn backward with respect to the earth's rotation at the rate of one revolution in 24 hours. At any point between the pole and the equator, as shown in figure 19G3 (B) the wheel appears to gyrate once every 24 hours about an axis parallel to the axis of the earth's rotation and in a direction opposite to that of earth's rotation.

This effect can be compensated for if the gyro can be made to precess slowly to the eastward at the same rate as the earth's rotation. The gyro's plane of rotation will then remain parallel to the horizontal plane. This is accomplished in the stable vertical by means of a *latitude weight* which is so arranged that the effect of the weight is to cause a downward pressure at the north point of the gyro wheel, resulting in an easterly precession. The position of the latitude weight is adjustable, so that it can be set for the latitude in which the ship is operating.

Actually, the mercury control system would tend to keep the gyro spin axis vertical, but if the mercury control were acting alone, the gyro would still tend to deviate slightly from the vertical as a result of the apparent precession caused by the earth's rotation. The latitude weight compensates for this error.

19G5. Mechanical construction

The Mark 41 stable vertical consists essentially of a *sensitive element* and a *measuring group.* The sensitive element is the heart of the instrument and consists of the gyro, gyro case, gyro gimbal, and a fork-shaped support known as the rotating fork.

Figure 19G4 shows the gyro proper. The wheel is carried on an axle supported by ball bearings at the upper and lower ends of the gyro case, the wheel and case forming the rotor and stator of a high-frequency induction motor. The squirrel-cage winding, consisting of solid conducting bars, is in the gyro wheel, while the wire stator windings are in the gyro case. A special motor-generator is provided to supply power at a frequency sufficient to drive the gyro at about 8,500 revolutions per minute.

The gyro assembly of figure 19G4 pivots within the gyro gimbal on a case axis perpendicular to the spin axis, as shown in figure 19G5. The gimbal ring, in turn, is supported by the arms of the rotating fork on the gimbal axis, which is perpendicular to both the case axis and the spin axis. This axis arrangement provides a universal mounting giving the gyro three degrees of freedom, and allows it to spin on a vertical axis, even though the rotating fork may vary its position from time to time.

The measuring group consists of a level gimbal, a crosslevel gimbal, and a training gear. Figure 19G6 shows the arrangement of the measuring gimbals. The outer gimbal is the level gimbal, supported at its trunnion bearings by the training-gear structure (main frame) as shown in figure 19G8. The level gimbal, in turn, supports the inner or crosslevel gimbal, so that its axis is perpendicular to the level-gimbal axis. At the lower end of the crosslevel gimbal the bearing for the rotating fork can be seen.

The entire sensitive-element assembly of figure 19G5 is mounted within the measuring-gimbal system of figure 19G6, being supported at its lower end by the rotating fork in its fork bearing, so that it is free to rotate within the measuring group. The complete assembly is shown in figure 19G7. A *gimbal rotation motor,* attached to the lower end of the crosslevel gimbal, is geared to the rotating fork and drives it at about 18 revolutions per minute. The fork turns the entire sensitive element at this speed within the measuring-gimbal system. This rotation is essential to the mercury control system.

19G6. Director train input

Since level and crosslevel angles must be measured with respect to the LOS, director train *B'r'* is received at the stable vertical to position the training gear. The training gear carries with it the main frame, which in turn supports the measuring group and the sensitive element. In this manner, the instrument is so oriented that the crosslevel axis lies in the direction of the LOS, with the level axis perpendicular to the LOS. Level, then, is measured in the LOS, and crosslevel 90° from the LOS.

Since the level gimbal axis is supported by the main frame, it lies in the deck plane, and level angle *L'* as measured by this gimbal, is measured in a plane perpendicular to the deck plane. On the other hand, the crosslevel gimbal is so mounted that it remains in the horizontal and measures crosslevel angle (*Zh*) in a vertical plane. These features of construction cause the stable vertical to measure *L'* and *Zh* in accordance with the definitions of article 19F21.

19G7. The follow-up system

The actual measurement of *L'* and *Zh* is accomplished by an electrical follow-up system. Figure 19G5 shows an electromagnet installed at the upper end of the gyro spin axis. This magnet remains in the true vertical because of the action of the gyro. Above the magnet but attached to the top of the crosslevel gimbal is an *umbrella* containing two figure-eight follow-up coils at right angles to each other, one for level and the other for crosslevel.

Roll or pitch of the ship will cause movement of the umbrella with respect to the magnet, inducing voltages in the follow-up coils by transformer action. The voltages so induced are amplified and rectified at a stable-vertical control panel, and are then used to energize level and crosslevel follow-up motors, which drive back through the gear trains shown in figure 19G8, causing the level and crosslevel gimbals to move. When the umbrella is back in its neutral position over the electromagnet, voltages are no longer induced in the coils and the follow-up motors cease to drive.

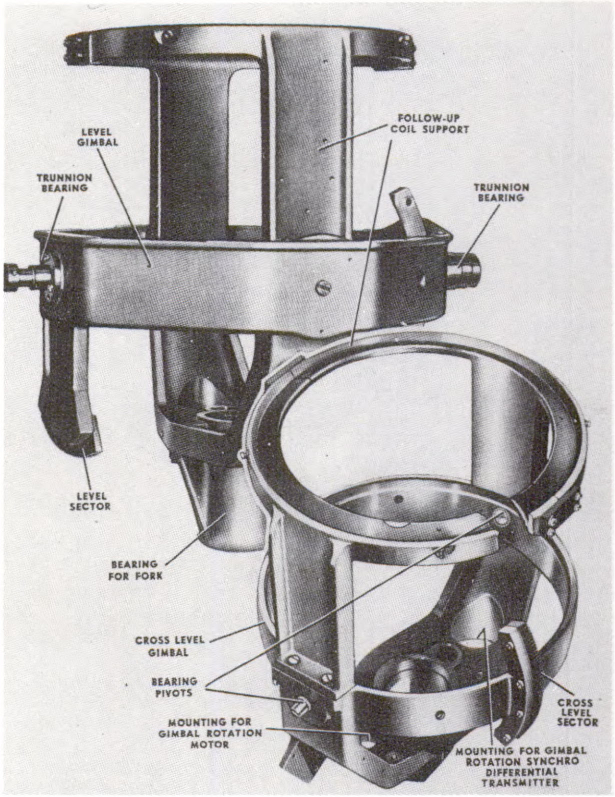


FIGURE 19G6.—Level and crosslevel measuring gimbals.

The follow-up coils are so constructed that they pick off voltages proportional to *L'* and *Zh,* respectively. The amount of rotation of the follow-up motors necessary to cause the gimbals to maintain the umbrella at the neutral point over the electromagnet is then a direct measure of level and crosslevel. These outputs are transmitted electrically and mechanically to the instruments requiring these values.

The response of the follow-up system is made sufficiently sensitive to cause the umbrella center to *remain* very nearly in line with the magnet. The motors drive practically as soon as displacement begins, so that the measurement of *L'* and *Zh* is continuous and almost instantaneous.

An *anti-hunt unit* is installed at the control panel, and operates to shut off the power to the motors slightly before the neutral position is reached, preventing the umbrella from over-running the neutral position and driving back toward it again.

19G8. Mercury cut-out valves

The mercury control system has already been described. It normally operates to keep the gyro axis in the vertical.

At times, however, certain irregularities of ship motion, such as sharp turns and speed changes, occur which would cause an irregular flow of mercury, tending to disturb the gyro rather than to right it. To prevent mercury flow at such times, a *mercury cut-out valve* closes, blocking the connecting tube. This

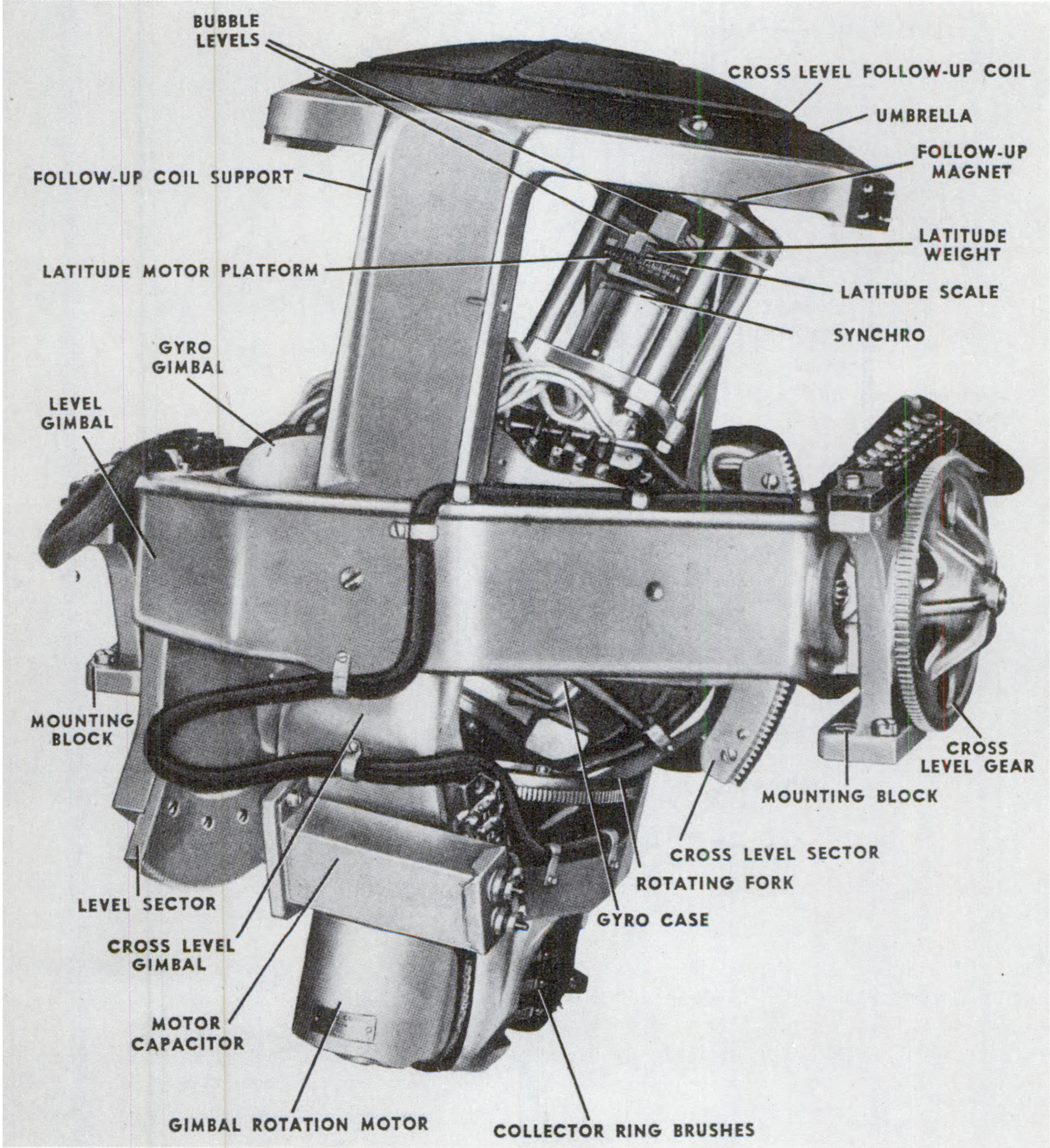


FIGURE 19G7.—Complete assembly, showing sensitive element and gimbals.

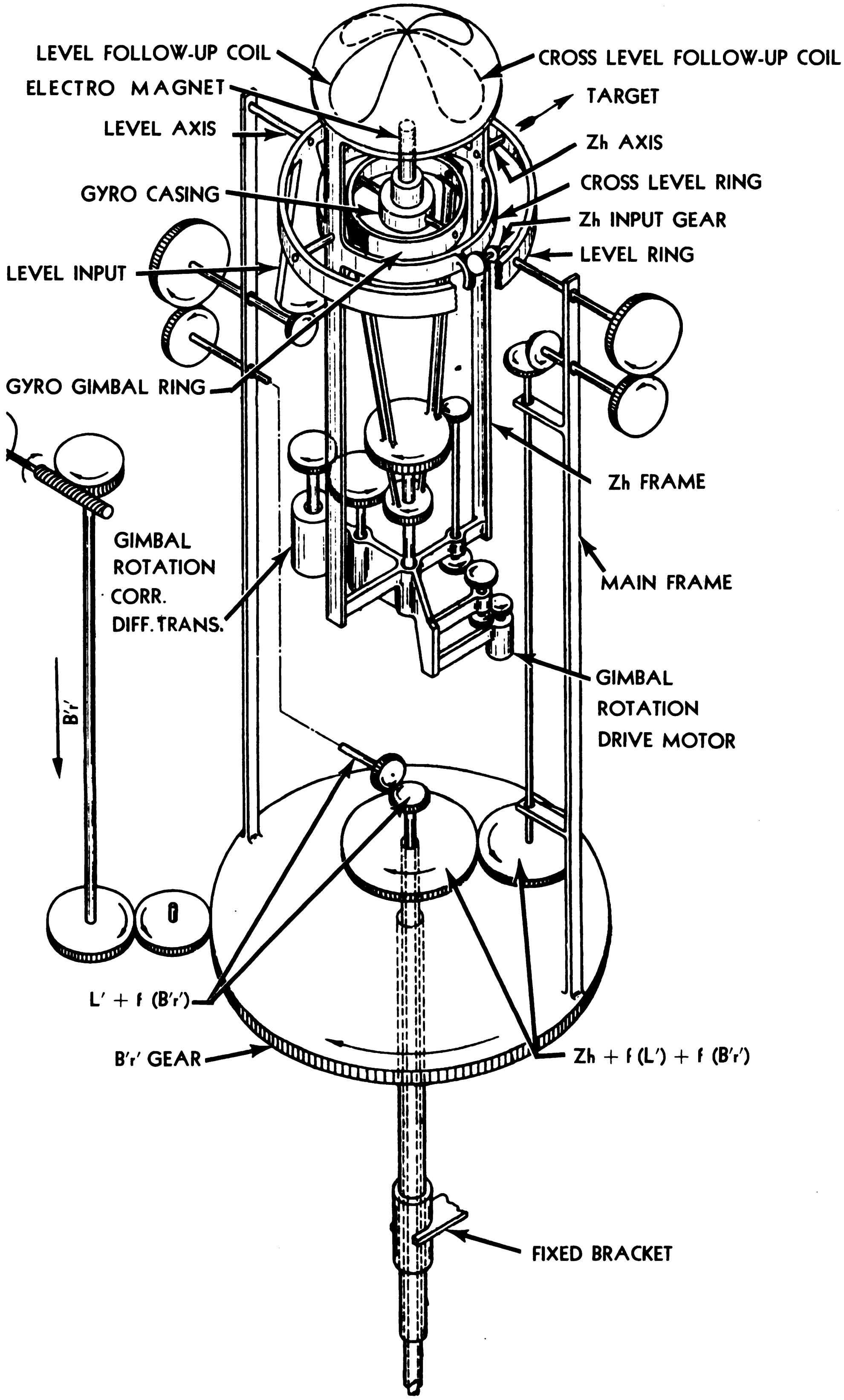


FIGURE 19G8. —Stable vertical, schematic arrangement.

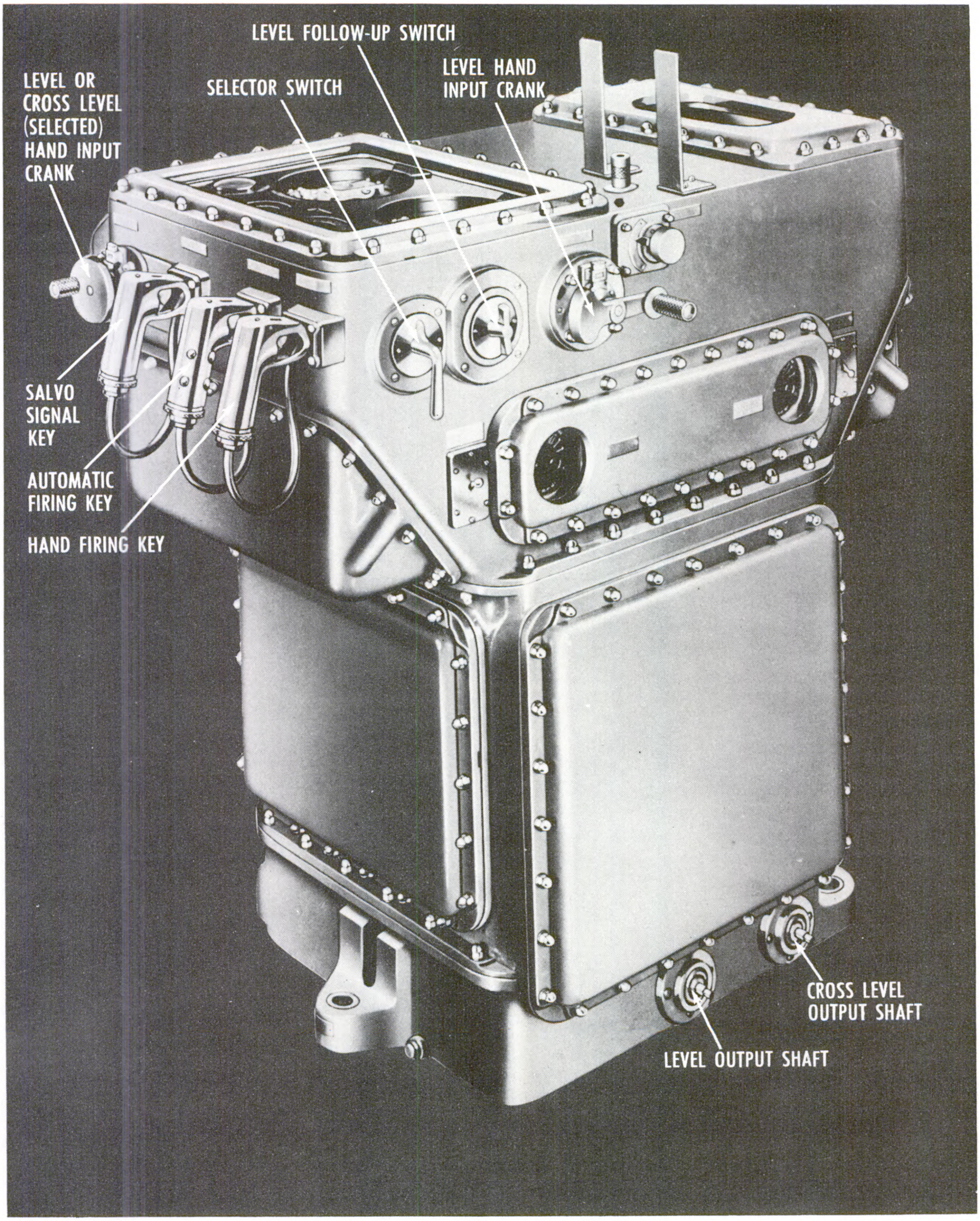


FIGURE 19G9. —Gun Director Mark 41 (stable vertical).

valve is operated automatically by a cut-out control on the control panel. During starting, the valve should remain open and therefore is made inoperative, since ship motion has no appreciable effect on the settling of the gyro. After the gyro has settled, the valve is connected to the automatic control.

19G9. Latitude motor input

It will be recalled that the latitude weight must always apply its downward force at the north point of the gyro wheel, and that the amount of force must be varied in accordance with the ship's distance from the equator. This is accomplished by manually moving the latitude weight inward or outward in its mounting. It is usually considered sufficient to make a latitude setting once a day.

The sensitive element continuously rotates at 18 rpm, and the entire assembly is oriented to the LOS by $B'r'$. Since the latitude weight is mounted at the upper end of the gyro spin axis as shown in figure 19G5, provision must be made to cancel out the effects of the rotation and the $B'r'$ input. This is done by mounting the latitude weight on the rotor of a synchro known as the latitude motor. The stator rotates in accordance with the inputs of 18 rpm and $B'r'$, but the rotor carrying the latitude weight is positioned by a signal impressed on the windings of the stator. This input signal is made up of $Co+B'r'+18$ rpm, with the result that the rotor keeps the weight positioned in the north-south plane.

The input is obtained by combining the stable-vertical inputs of Co and $B'r'$ in a differential generator to get an output of $Co+B'r'$. This output is then combined in a second differential generator with 18 rpm from the gimbal-rotation motor, to give $Co+B'r'+18$ rpm, which is used as the input to the latitude-motor stator.

19G10. Manual follow-up

The L' and Zh follow-up motors normally keep the umbrella positioned automatically over the gyro axis. Usually, then, the level and crosslevel hand input cranks are disengaged and the L' and Zh follow-up switches are set at AUTOMATIC. Should either follow-up motor fail, the appropriate follow-up switch is set at MANUAL and its associated hand crank is engaged. This action breaks the circuits to the follow-up motor and transfers the umbrella's pick-off signal from the amplifier unit to the galvanometer shown on the face of the instrument. The hand crank is then turned, to reposition the gimbal and umbrella over the magnet by keeping the galvanometer needle as nearly as possible in its zero position. Manual follow-up can be used instead of either or both follow-up motors.

Chapter 20

MAIN-BATTERY SYSTEMS

A. General

20A1. Introduction

Main-battery fire control systems in battleships and cruisers, other than antiaircraft cruisers, are designed primarily to handle the surface fire control problem, discussed in chapter 19. Although the present trend is toward development of automatic major-caliber guns capable of handling either the surface or the air problem, the great majority of main-battery systems now installed have very limited secondary provisions for antiaircraft fire.

The control of turret batteries against aircraft is made possible on most ships by interlocking arrangements between the main battery and the dual-purpose systems. The variety and complexity of these cross-connections preclude their analysis in this text.

20A2. System elements

The principal elements of a main-battery fire control system are located in four types of stations aboard ship. These stations are:

1. The control stations.
2. The aloft gun directors.
3. The plotting rooms.
4. The turrets.

20A3. Control stations

The Gunnery Officer has a station of his own, accessible to the Commanding Officer, and better protected than the gun directors. In battleships and some cruisers, this station is protected by heavy armor and is known as the fire control tower. In many ships there is a similar station aft from which all or part of the main battery may be controlled.

Either or both of these stations may be equipped to take over many of the functions of both the director and the plotting room in case of casualty, or they may serve merely as supervising and observing stations. In either case periscopes and indicating equipment are installed. In addition, there may be some of the following equipment:

1. Auxiliary gun directors, such as the Mark 40 or Mark 55.
2. Auxiliary computers (Mark 3 or Mark 6).
3. Control consoles, as well as indicators, for the Radar Equipment Mark 13.
4. An independent radar equipment (Mark 27).
5. A stable element (Mark 6) for use with the auxiliary computer.

20A4. Aloft gun directors

All battleships and cruisers have two primary gun directors, each equipped with both a radar and a rangefinder. The forward primary director is also the ship's primary spotting station and is usually under the direct personal command of the ship's leading spotter.

Cruisers of the *Baltimore, Oregon City, Cleveland, Fargo*, and *Brooklyn* classes are equipped with Gun Directors Mark 34 of various Mods. This director mounts a Rangefinder Mark 45. New heavy cruisers of the *Salem* class have Gun Directors Mark 54, which differ from the Mark 34 in having more complete provisions for control of the main battery against aircraft. The accompanying rangefinder is the Mark 66.

Battleships of the *North Carolina, South Dakota*, and *Iowa* classes and large cruisers of the *Alaska* class mount Gun Directors Mark 38, equipped with Rangefinders Mark 48. This director differs from the Mark 34 principally in that it does not provide a stand-by source of gun orders as does the Mark 34.

Radar Equipment Mark 13 is used with all directors mentioned, although some of the older ships still have the earlier Radar Equipment Mark 8. Some of the subassemblies of the radar are not physically located in the director.

20A5. Plotting rooms

Main-battery plotting rooms, located below the waterline and inside the armor belt, characteristically contain:

1. Rangekeepers, including associated graphic plotters. Various modifications of the Rangekeeper Mark 8, differing from each other chiefly in the ballistic cams, are built for use with the following guns: 16"/50 caliber, 16"/45 caliber, 12"/50 caliber, 8"/55 caliber (both types), and 6"/47 caliber.

2. Stable-vertical gun directors. *South Dakota* class battleships are equipped with the Mark 43, while all the other ships under discussion use the Mark 41.

3. Some units of the radar equipment.

4. A fire-control switchboard and an associated battle-telephone switchboard.

5. Various indicators.

Cruisers, except for the *Salem*, and *Worcester* classes, have one main-battery plotting room, containing only one rangekeeper and stable vertical. In case of casualty or divided fire, auxiliary equipment and procedures must be used. Battleships and the *Salem* and *Worcester* class cruisers have duplicate rangekeepers and stable verticals, located in some ships in the same compartment, in others in separate compartments.

20A6. Turrets

As mentioned in chapters 7 and 10, some of the ship's fire control equipment is located in the turrets. Except for the latest types of turrets, equipped with radars instead of rangfinders, there is little difference between classes of ships in this respect.

B. A Typical System

20B1. Introduction

In this section, the system installed on the *Baltimore* and *Oregon City* classes of heavy cruisers will be described. This system does not vary in principle from other main-battery systems. The discussion will include brief descriptions of the stations and instruments comprising the system, illustrations, and explanations of the connections between them, and details of several ways in which the system is used to track a target and to position and fire the turret guns. It is concerned primarily with the functioning of the various pieces of equipment as parts of an integrated system, and the part which the officers and men of the ship play in operating this system.

20B2. General features of the system

The main battery consists of nine 8"/55 caliber guns mounted in three triple gun turrets. Turrets 1 and 2 are forward and turret 3 aft. All turrets can be trained through 300° (150° on either side of the centerline). The guns can be elevated 41° above and depressed 5° below the deck plane. Each gun is independently controlled in elevation.

The fire control system is designed to aim and fire the guns at moving surface targets within the range of about 30,000 yards (approximately 15 miles).

Preliminary information concerning targets is transferred to the fire control party through the target-designation system, which has associated equipments located at various points on the ship, such as search-radar consoles and lookout stations. This information is combined with other estimated or measured quantities, whereby the system computes sight angle and sight deflection. The system also measures level and crosslevel, and from all these data computes gun orders.

20B3. Principal system components

The system of fire control used on these ships is known informally as the Gun Director Mark 34 system.

Gun directors. The two primary directors are located above the main-battery fire control stations. Their basic function is to determine the LOS to the target by pointing the telescopes or the radar antenna toward it. Range is measured by the radar or the rangefinder in the director and, together with target bearing, serves to locate the target's present position. Under certain conditions, such as divided fire or casualty operation, the directors may assume some of the functions of the stable vertical and rangekeeper by measuring level and crosslevel and computing gun orders, using data furnished by auxiliary computing equipment. Corrections are made at the director for both horizontal and vertical parallax, based on the distance to the ship's reference point and the mean height of the gun trunnions, respectively.

Plotting room. The plotting room (Plot) contains a stable vertical, a rangekeeper, some units of the radar equipment, and a main-battery switchboard.

The auxiliary main-battery switchboard is located in the after gyro room. It is connected to the system in such a way that it can substitute for the main-battery switchboard in Plot if the latter becomes inoperative. By means of this switchboard any director can be connected to any turret or group of turrets without using main-battery plotting-room facilities.

Turrets. Within the turret are three elevation receiver-regulators and a train receiver-regulator. These instruments control the hydraulic gear by which the turret is trained and the guns elevated in accordance with gun orders. These orders may originate at the plotting-room rangekeeper, at either of the aloft directors, or locally at the pointer's and trainer's handwheels.

The turret also contains one turret-train indicator and transmitter, and three gun-elevation indicators. These are follow-the-pointer units by means of which gun orders from the plotting room or elsewhere may be received electrically to be matched by handwheel operation. The train transmitter sends turret train for information purposes only to turret train indicators in various stations.

Also provided is a sight setter's indicator, by means of which the sight setter sets the sights and supplies certain correction quantities for train and elevation instruments. In order to be independent of the rest of the system for local fire control, if necessary, the turret is also equipped with pointer's and trainer's gun-sight telescopes, a rangefinder, and an auxiliary computer.

Synchro transmission. The synchro transmission system transmits data and orders between the elements of the system. The single lines each represent a group of conductors. Selector switches at each fire control station and at each turret are provided to connect the turrets with either the main-battery or auxiliary main-battery switchboards. At the switchboards provisions are made for interconnecting the directors and turrets.

The firing circuits permit the guns to be fired by firing keys at various stations—in the directors, the plotting room, or the turrets. These keys are used for electric firing by hand keys. In automatic key firing, the guns are fired when contacts in the stable vertical are closed at a selected value of level or crosslevel. Ready lights and salvo signals are provided at all stations. Time-of-flight signals are provided at the directors and fire control stations, and in the plotting room.

20B4. Capabilities of the system

The fire control system may be operated in several different ways. This flexibility permits fire to be maintained in the event of casualty to parts of the system, and provides for firing at two or more targets at the same time.

Types of fire control. The different types of fire control are distinguished by the source and transmission route of the gun orders. The types of control are primary, secondary, auxiliary, local, and antiaircraft. These types, except the last named, are shown in figure 20B1.

In *primary* fire control, the target is tracked by one of the directors; gun orders are computed by the rangekeeper in Plot and transmitted to the turrets *via* the main-battery switchboard.

In *secondary* fire control, the target is tracked and gun orders are computed by one of the directors, with data supplied from the rangekeeper in Plot or from auxiliary equipment. Gun orders pass to the turrets *via* the main-battery switchboard.

Auxiliary fire control is similar to secondary fire control, except that the auxiliary switchboard is substituted for the main-battery switchboard in Plot.

In *local* fire control each turret utilizes local instruments and sights to solve the problem and aim the guns, and operates as a self-contained unit.

For *antiaircraft* firing, provision is made to connect the main-battery system to receive gun orders from the secondary (dual-purpose) battery system, so that the 8-inch guns may be used for antiaircraft fire. The long range of these guns makes them useful for firing on enemy planes which are grouping for attack beyond the range of the 5-inch guns. Differences in ballistics between the secondary-battery and the main-battery guns make necessary the application of corrective spots to the gun orders computed in the secondary-battery computer. This limits the effectiveness of this system against aircraft.

Methods of gun laying. Figure 20B1 is a schematic diagram showing the available types of fire control and methods of gun laying and of turret drive. The different methods of operation by which the guns may be positioned are: *automatic* gun laying, in which the receiver-regulator controls the A-end; *indicator* gun laying, where an indicator is used to guide the handwheel operator; or *local* gun laying, where the gun-sight telescopes are so used.

Methods of drive. The methods by which the handwheels control the driving of an element are *local* power drive and *hand* drive. In local power drive the handwheels are geared to the receiver-regulator, which in turn controls the A-end of the hydraulic gear. In hand drive the handwheels are geared to the A-end and thus control the hydraulic drive directly. Both of these methods of drive use an electric motor to supply power to the hydraulic gear for moving the element; the handwheels govern only the volume of fluid that is pumped by the A-end. In *manual* drive the electric motor is inoperative, so the A-end is driven by manpower applied to an emergency hand crank. The operator's handwheels (pointer or trainer) function as in hand drive.

In primary fire control, secondary fire control, and auxiliary fire control, either automatic or indicator gun laying may be employed. In local fire control, local gun laying must be employed. In both indicator and local gun laying, either local power or hand drive may be used, but in automatic gun laying these methods are not applicable.

Means of firing. Gun firing may be either by local key or by master key or by percussion; but percussion is used only when electric firing fails. Remote master keys at various stations in the ship may be used. In primary fire control, selected level or selected cross-level automatic key firing may be done automatically by the firing mechanism in the stable vertical. This method is not available in other methods of fire control.

C. Gun Directors

20C1. General

Each cruiser is equipped with two Gun Directors Mark 34—No. 1 forward and No. 2 aft, mounted near the main-battery fire control stations. The director is enclosed in a shield which supports the rangefinder and radar antenna as shown in figure 20C1.

The directors may be used to measure the target coordinates (bearing, elevation, and range) in various manners, which must be defined.

Aiming is the process of establishing target position in bearing and elevation. *Aim* is classified as to type by the instrument employed: *i. e., radar aim* indicates the determination of bearing and elevation by radar; *optical aim,* by telescope. If, in association with determination of bearing by observation, elevation is determined by stabilizing instruments rather than by observation, the procedure is known as *partial radar* (or optical) *aim.* When neither bearing nor elevation is established by observation, but both by calculation of data otherwise introduced, the process is designated as *generated aim.*

Ranging is the process of establishing target distance from the firing ship. Like aiming, it is classified by means as *radar ranging, optical* (rangefinder) *ranging,* or *generated ranging.*

Both aiming and ranging may be either *continuous* or *intermittent.* Intermittent aim is directly associated with intermittent stabilization, and is therefore discussed in connection with the stable vertical in article 20E2. Intermittent ranging is employed when the means of ranging is by rangefinder; it is rarely used with radar ranging.

Continuous aim and ranging may be classified as to method as *automatic, aided,* or *manual.* Manual aim and ranging signify the positioning of the instrument used by the operator by hand in accordance with his observations. Aided operation means the positioning of the instrument in accordance with signals received from the rangekeeper, corrected as necessary by the operator as he observes the target (optically or by radar). Automatic ranging and aiming are not applicable to the system under discussion.

Each Gun Director Mark 34 is equipped to measure the three target coordinates, optically or with its associated radar equipment, and to transmit the values therof (bearing and elevation after correction for parallax) to the rangekeeper. In addition, the director is equipped to take over some of the functions of the rangekeeper and stable vertical. It may be used to measure crosslevel optically. Under secondary fire control and auxiliary fire control procedures, and when supplied with sight angle and sight deflection from the auxiliary computer, the director can correct these quantities for trunnion tilt, combine them with level (director elevation) and director train respectively, and transmit the sums as gun elevation order and gun train order to the turrets *via* the main or auxiliary switchboards. In addition to these functions as instruments, the directors serve as lookout stations from which targets can be located and the fall of shot spotted.

20C2. Description

The director proper provides stations for a crew of eight men within the shield. At the rear of the director are stations for the trainer, pointer, spotter, and radioman. The rangereader's seat is attached to the shield. At the front of the director (figure 20C2) are stations for the crossleveler and two sight setters. Each station provides a seat and the handwheels, switches, dials, optics, and other apparatus used by the operator. The spotter is provided with binoculars, which are mounted on the roof of the director shield.

The instruments and assemblies within the director include the following:

1. The trainer's units.
2. The pointer's units.
3. The crossleveler's unit.
4. The sight setter's unit.
5. The computing units.
6. The director drive system.

20C3. Trainer's units

The trainer's units are those which implement or facilitate tracking the target in bearing. They may transmit director train, train designation, and gun train order, and receive train designation and own-ship course.

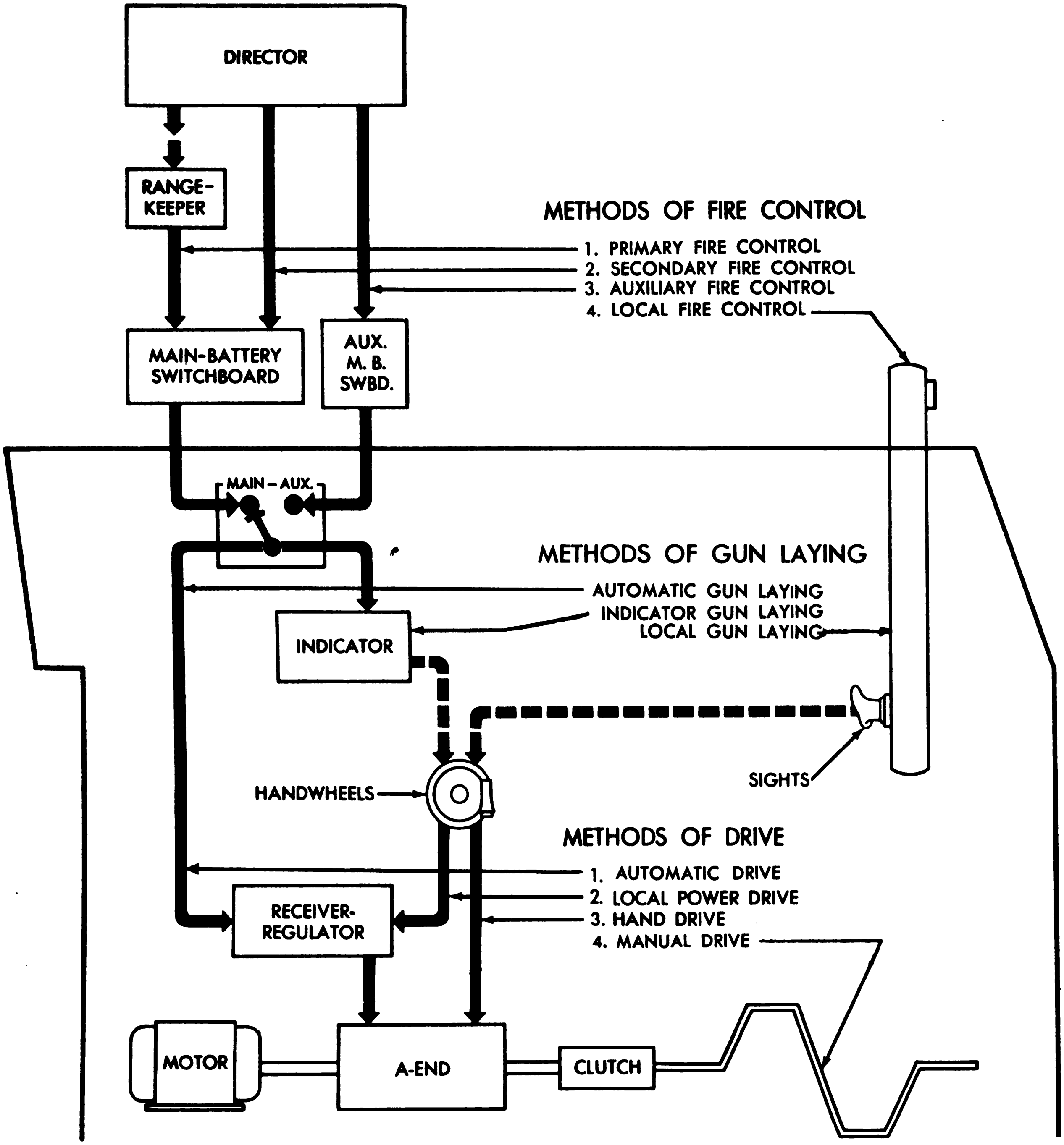


FIGURE 20B1.—Schematic of the available methods of fire control, of turret operation, and of turret drive.

The trainer tracks a visible target by turning his handwheels to bisect the target image with his telescope vertical crossline, thus training the director and determining director train. He may also use an auxiliary radar indicator for tracking the target in blind firing. As the director is trained, the radar antenna mounted on the shield turns with it. When the target echo on the radar scope is bisected by the center bearing line, the director is trained on the target, and the correct value of director train is determined. Director train is corrected in all forms of fire control by the horizontal parallax mechanism which receives a parallax range input from the sight setter's unit. In primary control, corrected director train is transmitted by two sets of synchro generators; one set normally transmits observed director train to the rangekeeper, while the other set transmits train designation to other stations for information. In secondary and auxiliary control, deck deflection (that is, sight deflection corrected for trunnion tilt), received from the director computer unit, is added to corrected director train, and the result is transmitted by the observed-director-train synchros as gun train order.

20C4. Pointer's units

The pointer's units measure director elevation (which may be used as a substitute for level) corrected for vertical parallax. In one form of primary fire control, the director may substitute for the stable vertical in Plot, at which time the movement of the pointer's handwheels operates synchro generators which transmit director elevation to the rangekeeper. In another, it transmits director elevation to the stable vertical in Plot for positioning the automatic firing contacts for automatic key firing, with selected values of level. In secondary and auxiliary fire control the pointer transmits level mechanically to the director computer units, which position the pointer's unit synchros to transmit gun elevation order to the turrets *via* the switchboard. Follow-the-pointer dials provide level indication from the stable vertical in Plot or from an auxiliary stable element in the after fire control station, when the pointer is unable to keep his telescope crossline on the target or horizon. The pointer's handwheels also keep the trainer's telescope on the target in elevation.

20C5. Crossleveler's unit

The crossleveler's equipment is used only in secondary or auxiliary control. It measures crosslevel by sighting as desired at either of two points on the horizon 180° apart, at right angles to the trainer's line of sight.

Crosslevel is transmitted mechanically to the computing units in the director for the computation of trunnion-tilt correction in the formulation of gun orders.

For stabilization a crosslevel indicator in the after director receives crosslevel from the auxiliary stable element. By matching pointers on the dials, the crossleveler transmits crosslevel to the director computing units.

20C6. Sight setter's units

There are two sight setter's units, one for sight angle and one for sight deflection. The sight-angle unit consists of two follow-the-pointer dial groups, while the sight-deflection unit consists of a single follow-the-pointer dial group. Both units are operated in secondary and auxiliary control, receiving sight angle and sight deflection from the auxiliary computer in the fire control station, or from the rangekeeper, and relaying it to the director computing instruments. In primary control only sight angle is used. Sight angle is received from the rangekeeper, converted to parallax range, and used in computing parallax corrections for addition to observed director train and level.

20C7. Computing units

Mounted in the lower part of the director frame are two computing instruments, the trunnion-tilt corrector and the director-elevation corrector. These instruments are employed only in secondary and auxiliary fire control for the computation of gun train and gun elevation orders, using the following inputs: director train, level, crosslevel, sight angle, and sight deflection.

In primary fire control, the computing instruments are locked in their zero positions, so as not to interfere with the transmission of director train and level to the plotting room.

20C8. Director drive system

The director can be trained by three methods—automatic power, local power, and manual.

In the first method, *automatic power* drive, the director is trained automatically in response to an electric signal from the rangekeeper in Plot, which controls the amplidyne follow-up system. This signal (called $\Delta cB'r'$, increments of generated director train) is the computed change in bearing required to keep the director continuously on the target. If, in this control, the trainer's crosslines tend to drift off the target, he turns his handwheels to bring the director back on target and signals Plot that a revision of estimated target quantities in the rangekeeper set-up is needed.

In *local power* drive the amplidyne follow-up system may be controlled by the trainer's handwheels; or the trainer's or spotter's slewing controls may be operated to rotate the director rapidly through large angles of train.

In the two drive methods where power is employed, local and automatic, an amplidyne follow-up system is used.

In *manual* drive the trainer's handwheels are connected through a clutch to the training worm, and the director and shield are rotated solely by the power applied by the trainer to the trainer's handwheels.

20C9. Shield

The director is enclosed and protected partly by the stationary barbette and partly by the rotating shield. The shield supports the rangefinder and the radar antenna, which turn with it.

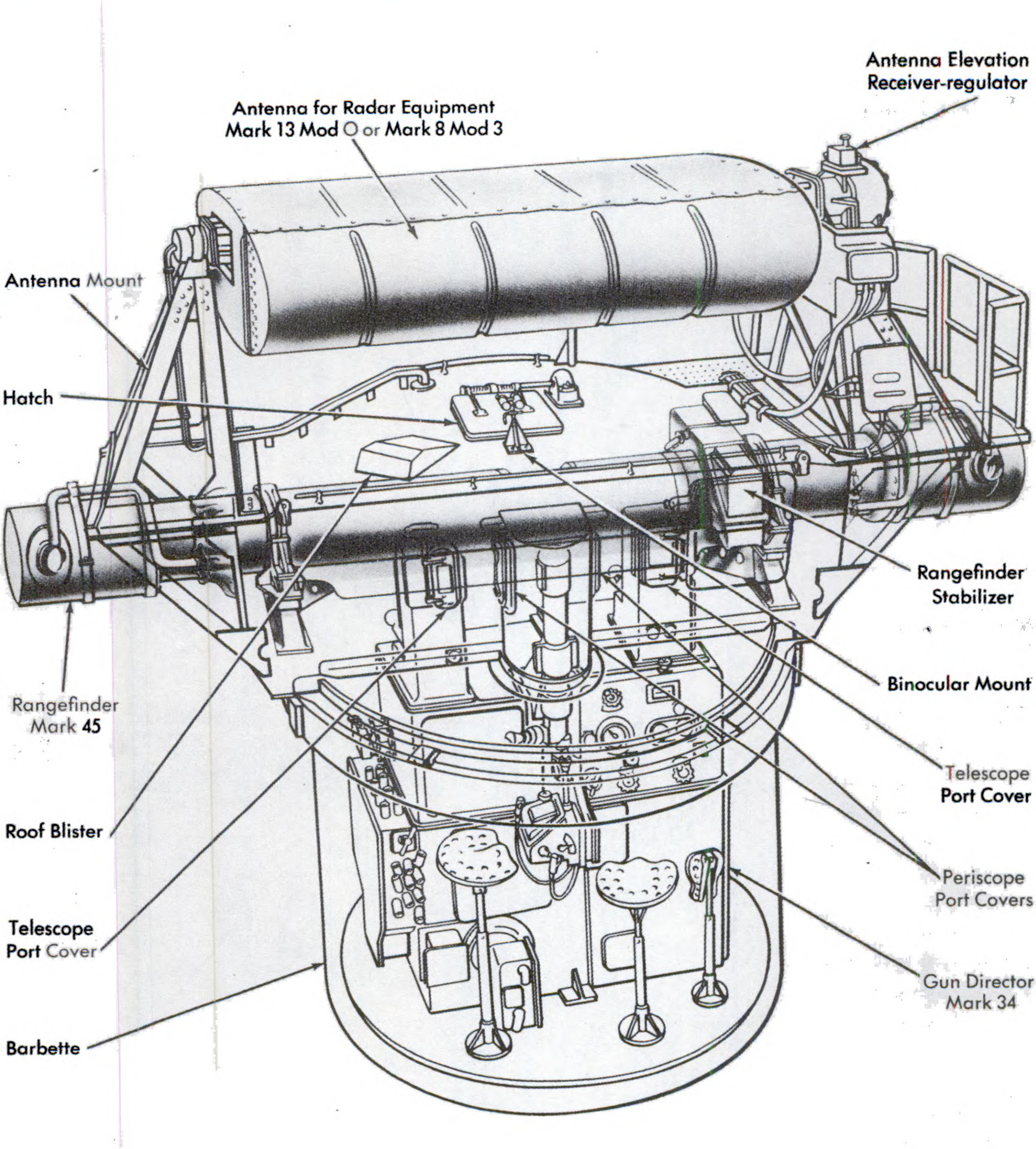


FIGURE 20C1.—The Gun Director Mark 34, front view.

20C10. Rangefinder and rangefinder equipment

The Rangefinder Mark 45 Mod 0 is a stereoscopic rangefinder with a base length of 18 feet. The range scale reads from 1,500 to 50,000 yards. Rangefinder range may be transmitted by means of the radar-range remote-control unit used in conjunction with the range indicator in this station. Two men operate the rangefinder—the spotter, who sights on the target and positions the wander marks, and the rangereader, who reads the range. The rangefinder is stabilized in level either manually, by means of a hand lever, or automatically. Automatic stabilization is accomplished by either of two devices: the rangefinder stabilizer or the

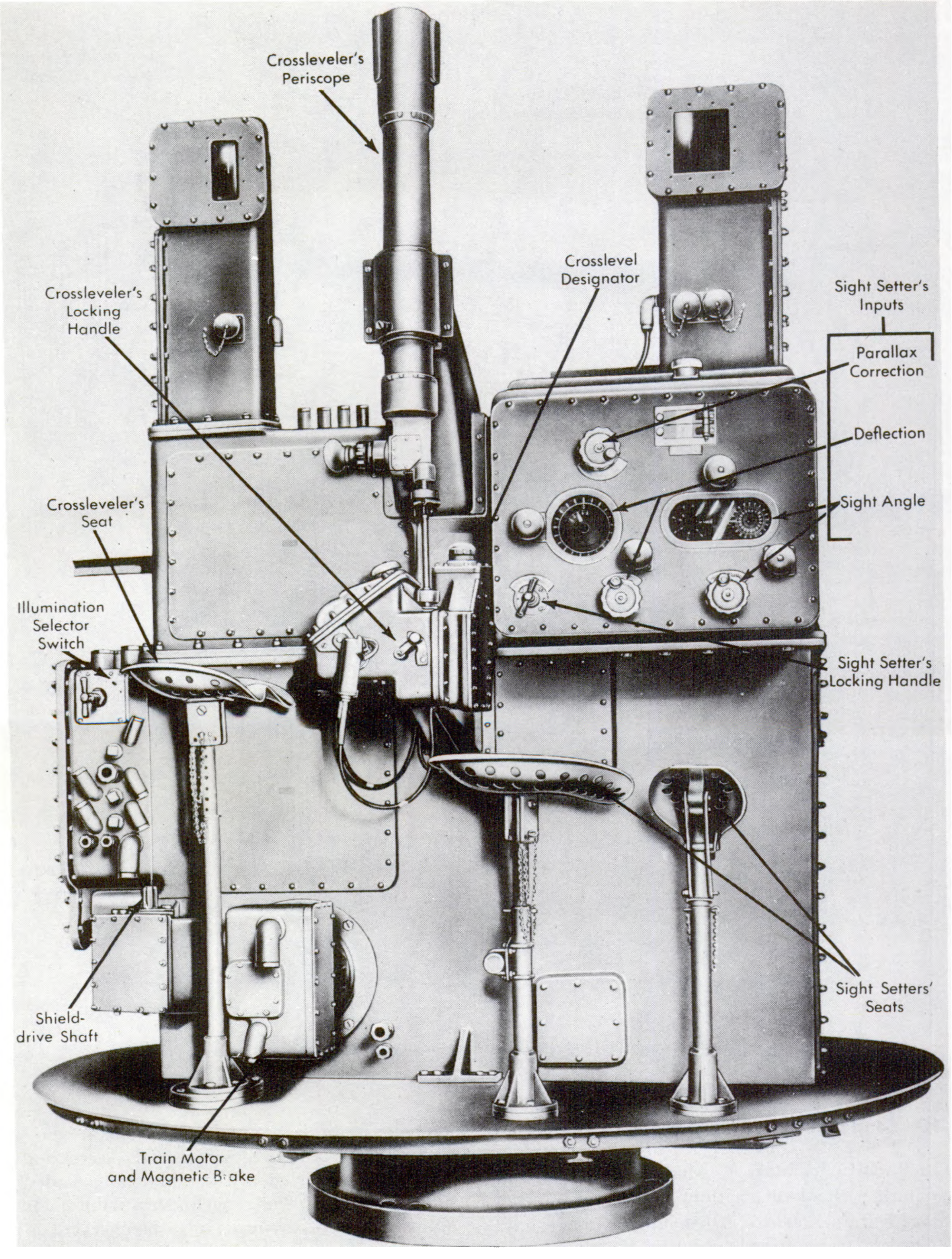


FIGURE 20C2.—Gun Director Mark 34, front view without shield.

rangefinder elevation receiver-regulator (whichever is installed). The rangefinder stabilizer is a self-contained device which includes a gyroscope and an electric-hydraulic follow-up system connected to the rangefinder through a linkage system. The elevation receiver-regulator follows a level signal received from the stable vertical in Plot (or from the auxiliary stable element), and thus stabilizes the rangefinder.

20C11. Radar equipment

Most of the radar equipment associated with the forward director is located in the plotting room; that for the after director is in the after fire control station. For either type of radar equipment an antenna mounted on top of the director shield is supported by the radar-antenna mount, which automatically stabilizes the antenna in level by means of a receiver-regulator. Level signals to this unit are relayed from the plotting-room stable vertical or the auxiliary stable element by the antenna-elevation corrector inside the shield. The operator turns a hand crank on the corrector to set the antenna at the desired elevation, after which it is held automatically in that position, regardless of roll or pitch. The radar antenna transmits a directed radar beam into space parallel with the director line of sight, and also receives target echoes. When the target echo is bisected by the center bearing line of the indicators, the director is on target. The antenna oscillates horizontally to scan an arc of 11.5°, ten times per second. The operator can substitute for the service antenna a dummy antenna and echo box, which are used for checking the performance of the system.

20C12. Inputs and outputs

The inputs to the Gun Director Mark 34 in primary fire control are:

1. Increments of generated director train.
2. Generated director train.
3. Sight angle.
4. Own-ship course.
5. Level.
6. Train designation.
7. Observed range.

Outputs of the director in primary fire control are:

1. Corrected director train (corrected for horizontal parallax).
2. Director elevation (not always used).
3. Range.
4. Train designation.

The inputs to the director in secondary or auxiliary fire control are:

1. Sight angle.
2. Sight deflection.
3. Own-ship course.
4. Level (after director only).
5. Crosslevel (after director only).
6. Train designation.

Outputs of the director in secondary or auxiliary fire control are:

1. Gun train order.
2. Gun elevation order.
3. Corrected director train.
4. Range.
5. Train designation (secondary fire control only).

D. Fire Control Stations

20D1. General

There are two main-battery fire control stations-- one located adjacent to the forward director and one near the after director. Figure 20D1 is a view of the after fire control station. Equipment in these stations supplies data to the directors when they are operated in secondary or auxiliary control, which makes them independent of the plotting-room equipment. Each station contains: an Auxiliary Computer Mark 3, which supplies sight angle and sight deflection to the directors; periscope mounts, used in locating targets; bearing indicators; a multiple turret-train indicator, and various switches and signal lights. In addition, asociated with the after tire control station is a Stable Element Mark 6, which supplies level and crosslevel to the after director for blind firing in secondary control or auxiliary control, and the radar control equipment associated with the after main-battery radar installation.

20D2. Computer Mark 3

One computer, such as that shown in figure 20D1, is located in each fire control station. The computer is an auxiliary instrument for use in secondary or auxiliary control, or when the rangekeeper in the plotting room is inoperative. It is smaller and simpler than the Rangekeeper Mark 8. The predictions are less accurate than are those of the rangekeeper, and therefore more corrections may have to be introduced by hand. Unlike the rangekeeper which produces gun orders, the auxiliary computer produces only sight angle and sight deflection.

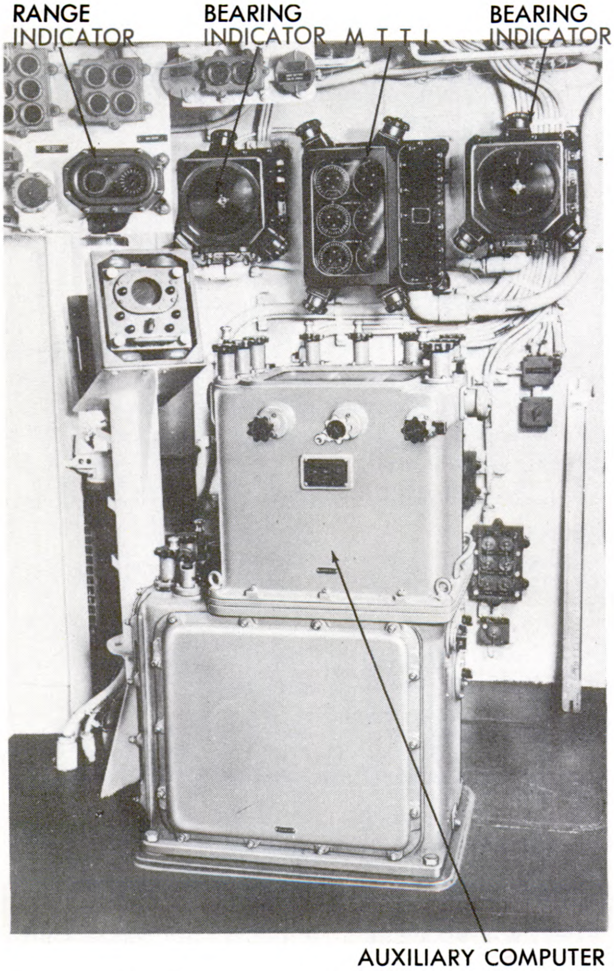


FIGURE 20D1.—After fire control station, showing the auxiliary computer and other instruments.

The auxiliary computer solves the fire control problem (for sight angle and sight deflection) for all movements of target and ship, and for wind across the line of sight. Director train is relayed to the computer by a target-bearing receiver.

Inputs and outputs of the auxiliary computer are shown in figure 20D3.

In secondary control, sight angle and deflection are routed to the director through the main-battery switchboard, from which they are also transmitted to the turrets. In auxiliary control, the values are transmitted directly to the director, and must be telephoned to the turrets.

The computer in the after control station, by means of a range transmitter mounted on the computer, transmits generated change of range to the radar equipment in the same station. This quantity is used in the radar equipment in such a manner that aided range tracking is provided for the radar operator in both secondary and auxiliary control. This permits constant check of the computer solution with observed optical range and radar scope indications.

20D3. Periscope mount

Each fire control station contains one or two periscope mounts. Each mount, as shown in figure 20D2, supports a rotatable periscope, whose relative bearing angle is shown on an attached bearing indicator. The instrument is used for locating targets, and information thus obtained is telephoned to other stations.

20D4. Bearing indicator

The fire control stations each contain two bearing indicators, which are also shown in figure 20D1. The bearing indicator indicates three quantities:

1. Relative target bearing, obtained by reading the fixed-dial plate graduations opposite the index on the ring dial.
2. True target bearing obtained by reading the

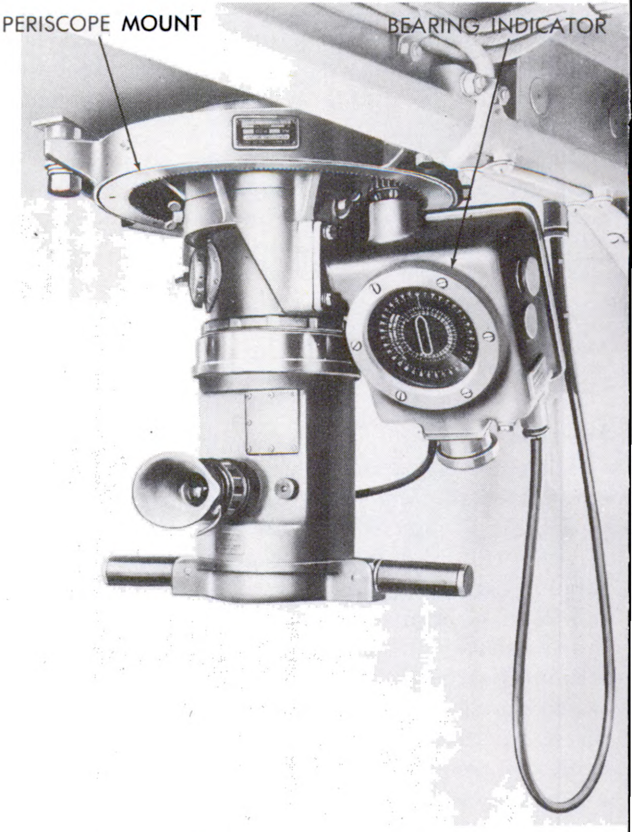


FIGURE 20D2.—Periscope and bearing indicator located in the fire control stations.

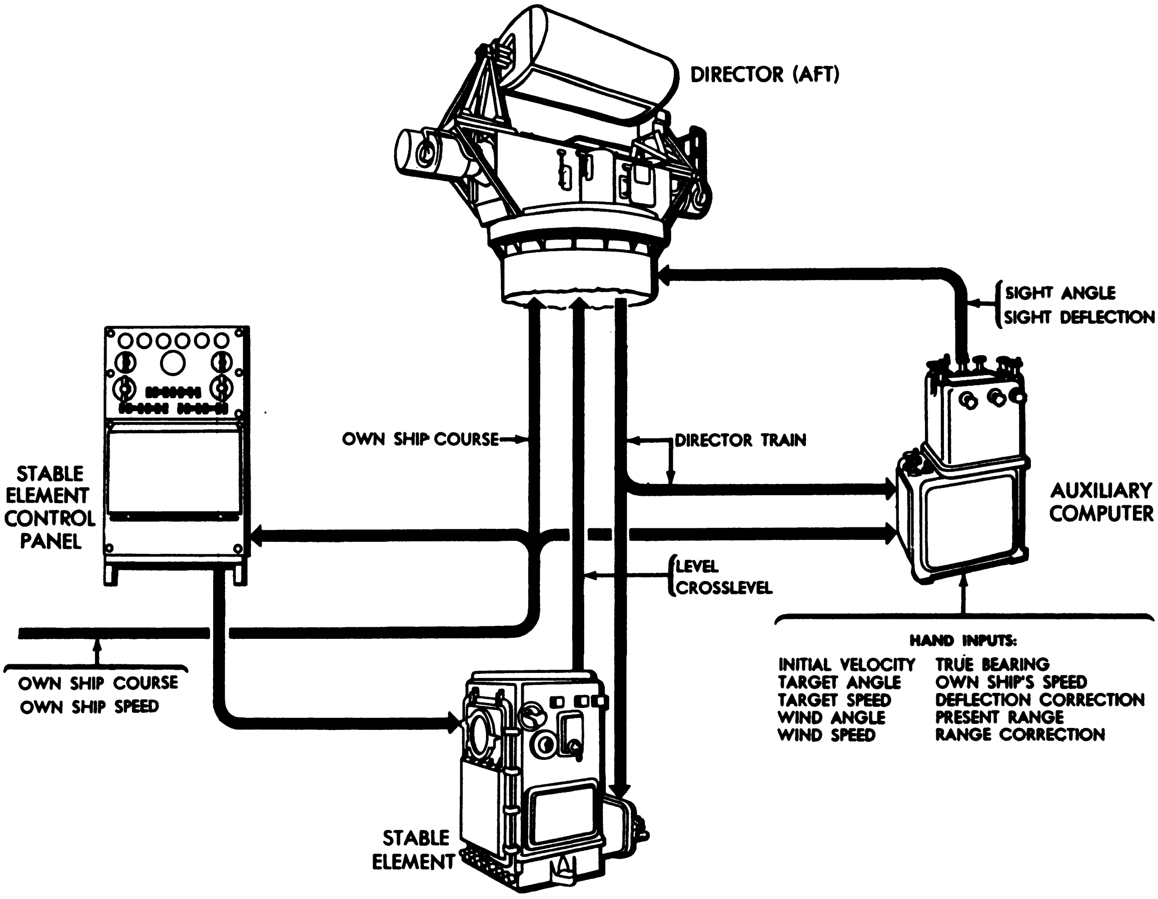


FIGURE 20D3.—Inputs and outputs of control aft. The forward control station has no stable element; therefore, no output of level and crosslevel.

inner dial graduations opposite the index on the ring dial.

3. Own-ship course, obtained by reading the inner dial against a fixed index.

Each bearing indicator receives director train from one of the aloft directors and own-ship course from the ship's gyro compass.

20D5. Multiple turret train indicator

A multiple turret train indicator (MTTI) is shown in figure 20D1 mounted on the forward bulkhead of the after fire control station. An identical instrument is provided in the forward fire control station. These instruments indicate modified turret train response for each of the three turrets on one set of dials, and show the difference between modified train response and gun train order on another set of dials. Modified train response is turret train corrected for horizontal parallax. Thus, the dials indicate whether or not the turrets are trained in accordance with gun train orders.

20D6. Stable Element Mark 6

This stable element, installed only in the after fire control station, measures level and crosslevel in the manner of a stable vertical and transmits these measured quantities electrically to the director (to operate the level and crosslevel designators) and to the radar antenna. This enables the director to be used in secondary (or auxiliary) fire control for blind firing, when optical means of measuring level and crosslevel cannot be used. The stable element is not used when the after director is in primary fire control. This stable element contains no automatic firing mechanism or firing keys.

Figure 20D3 shows the inputs and outputs of the stable element (and control panel), together with those of the auxiliary computer.

E. Main-Battery Plotting Room

20E1. Location

The main-battery plotting room is located opposite the secondary-battery plotting room. Its location below the waterline and beneath the armored deck is to ensure maximum protection from enemy action. The arrangement and location of the equipment differ somewhat among ships; figure 20E1 shows a typical installation, while figure 20E2 shows the main-battery switchboard.

The principal items of equipment in the plotting room are: the Gun Director Mark 41 (stable vertical), with its control panel; the Rangekeeper Mark 8, the radar equipment associated with the forward director, and the main-battery fire control switchboard. In addition to these principal items, there are a gun train order relay transmitter, bearing indicators, range indicators, multiple turret train indicators, a graphic plotter on the rangekeeper, director train indictors, telephone equipment, and various switches and signal lights. Some ships are provided with a dead-reckoning tracer in main-battery Plot.

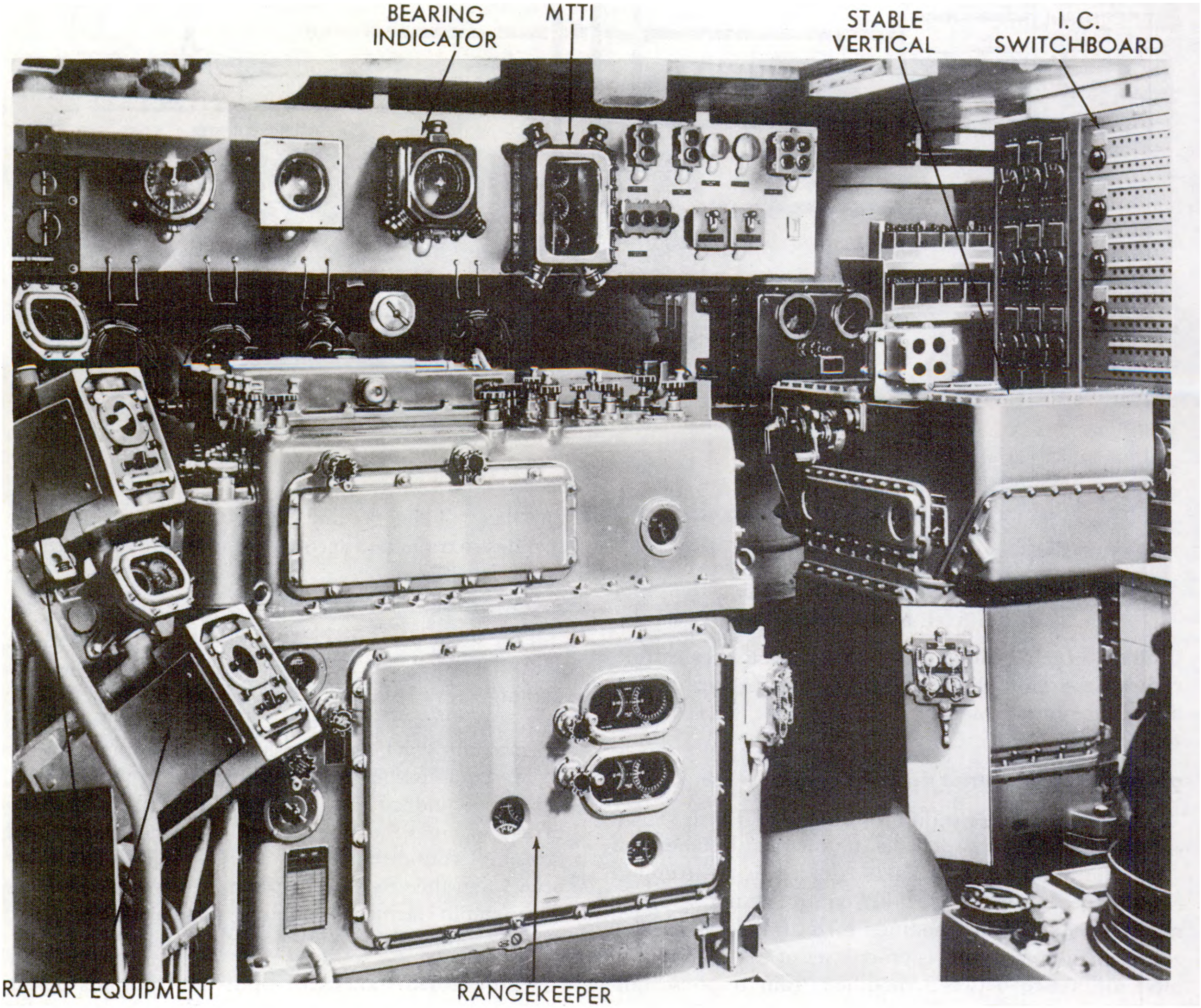


Figure 20E1.—Main-battery plotting room of a heavy cruiser.

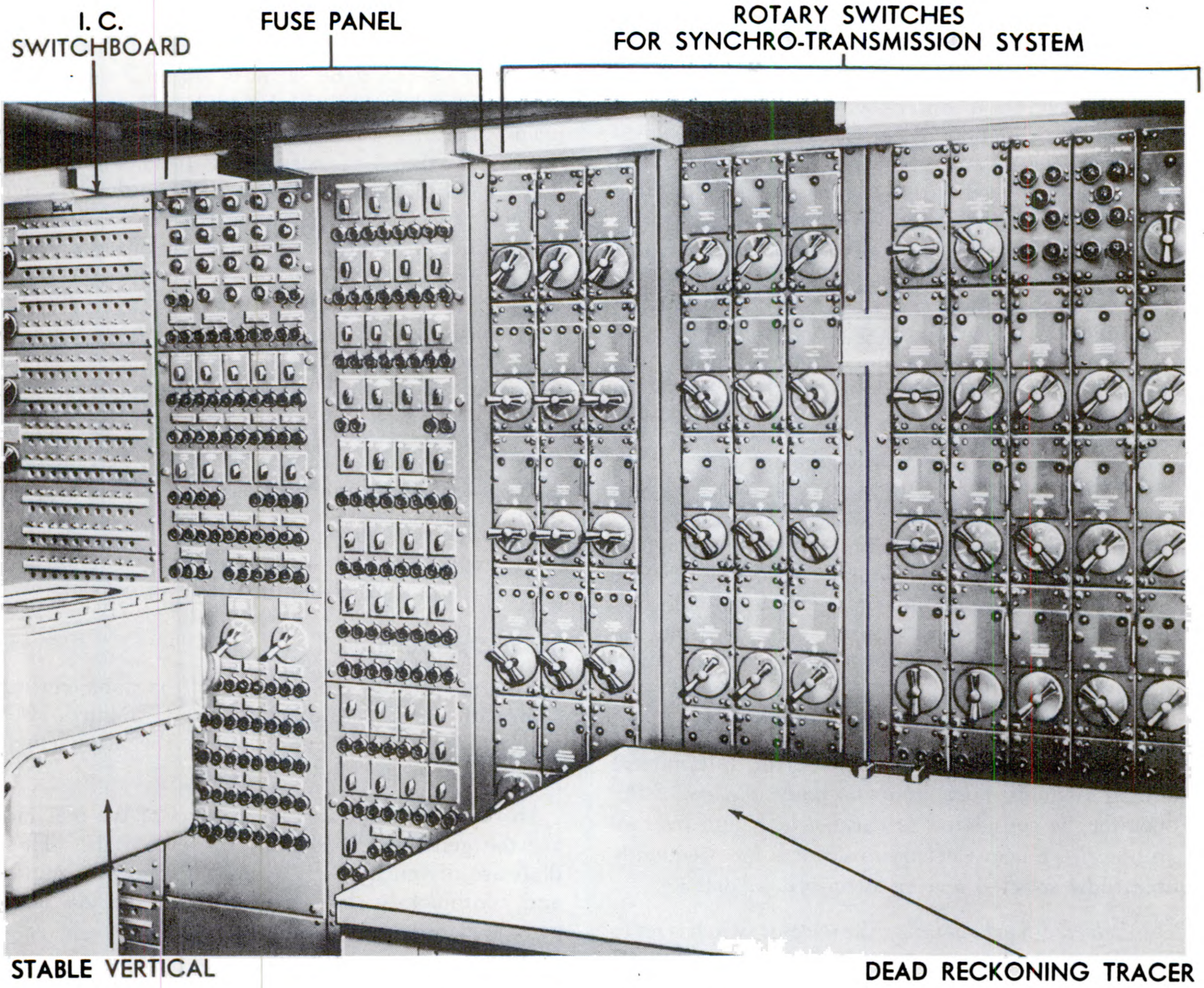


FIGURE 20E2.—The main-battery switchboard located at one end of the plotting room.

The plotting room is the primary source of gun train and gun elevation orders. To it, in primary fire control, are brought the data measured and estimated at the directors; from it are transmitted the data used to aim the gun.

20E2. Gun Director Mark 41 Mod 0 (stable vertical)

The general appearance of the stable vertical is as shown in figure 19G9.

In the previous chapter the stable vertical was discussed only as an instrument which designates and maintains the true vertical and its associated horizontal plane, and by so doing, continuously measures level and crosslevel. Another function of the stable vertical is its use as a remote firing station. The utilization of it as such is associated with methods of *aiming* designated as *continuous* and *intermittent.* Intermittent aim is that method of aim in which target position is continuously measured in one coordinate and periodically measured in the other; thus it may be subdivided into *selected elevation,* in which bearing is the element continuously measured, and *selected train,* in which elevation is the quantity continuously measured.

If continuous aim is in use, it is possible to fire the guns at any point in the motion of the ship in roll and pitch. Thus this method may be called, as it is on the nameplates of the stable vertical, "continuous fire," although this term must not be confused with the use of the same term to indicate a method of gun firing as defined in article 18A2.

Continuous aim is used under normal sea conditions.

The stable-vertical selector switch is set to CONTINUOUS FIRE, and both level and crosslevel as generated in the stable vertical are transmitted continuously to the rangekeeper. This results in gun train order and gun elevation order being continuously corrected for inclination of the deck. The guns may be fired by closing a hand firing key at the front of the instrument. Note that the gun maintains its position in space, while $E'g$ continuously changes as L' changes. Figure 20E3 illustrates continuous aim. (At times it is desirable to have the director pointer, rather than the stable-vertical operator, do the firing. This may be accomplished by keeping the stable-vertical key closed, so that the only break in the current is at the firing pointer's key. When his key is closed, the circuit is complete.)

Intermittent aim is used when sea conditions make it difficult for the guns to stay on target. In this method of aim the guns are not continuously stabilized but move with the ship, as shown in figures 20E4 and 20E5. It thus becomes necessary that the guns be fired only at such moments as aim is correct. To accomplish this, *master-key fire* from the stable vertical is used, preferably utilizing the automatic contact makers provided for this purpose.

Since at the stable vertical the quantities which are measured are level and crosslevel, the intermittent aiming methods must, from the point of view of the operator, be considered as *selected level* and *selected crosslevel*. Since selected crosslevel is less frequently used, only selected level is described in detail.

In *selected-level operation* the selector switch is set to LEVEL FIRE, and a fixed value of level angle is set into the stable vertical by hand (or electrically from the director in some cases). This value is usually selected so as to cause aim to be accurate and thus the guns to fire at about the middle of the ship's roll, and the same fixed value of selected level is transmitted from the stable vertical to the rangekeeper. It is apparent from figure 23E4 that since the angle between the deck and the gun ($E'g$) remains constant, there is one and only one position of the deck at which the aim is correct; that is, when the value of L', measured in the stable vertical, exactly equals the selected value of level ($L'j$) being transmitted. In order to ensure that the guns will fire at this instant, a set of firing contacts closes the circuit automatically when the above condition exists.

Any value of selected level $L'j$ may be chosen. Figure 23E4 shows the special case where $L'j=0$, and figure 23E5 is an example where $L'j=5$ degrees.

Selected-crosslevel operation is similar to selected-level, except that transmission of level remains continuous while transmission of crosslevel is fixed.

20E3. Operation

Figure 20E6 shows a top view of the stable-vertical face, with the various dials indicated. Figures 19G9 and 20E7 are side views, showing the arrangement of cranks, switches, and firing keys.

In the front right and left corners of the dial face are the generated level and crosslevel dials. These dials are driven by the L' and Zh follow-up motors and continuously show values of L' and Zh being generated.

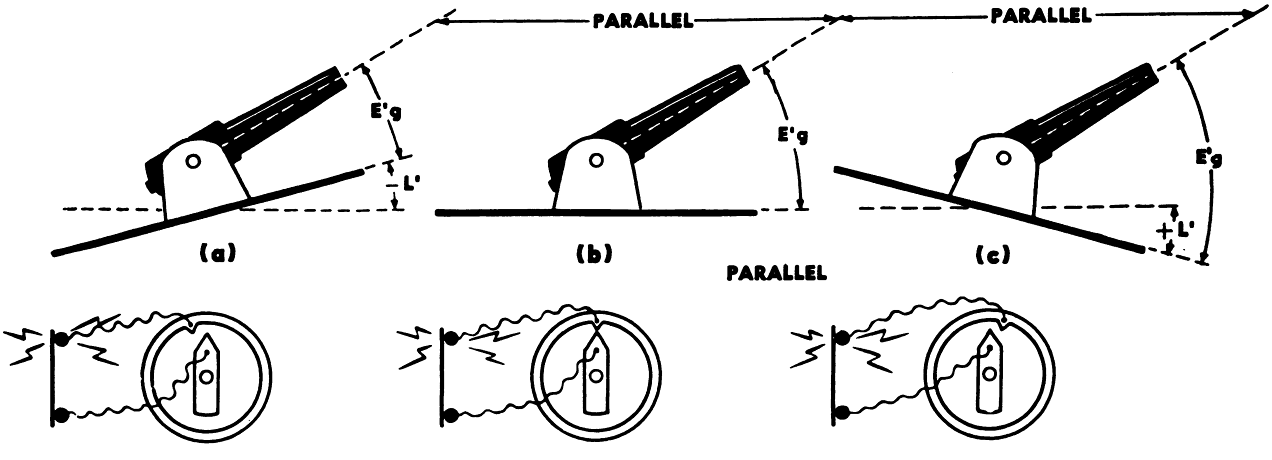


FIGURE 20E3.—Guns continuously stabilized—can be fired at any time. Automatic firing contacts are bypassed by selector switch.

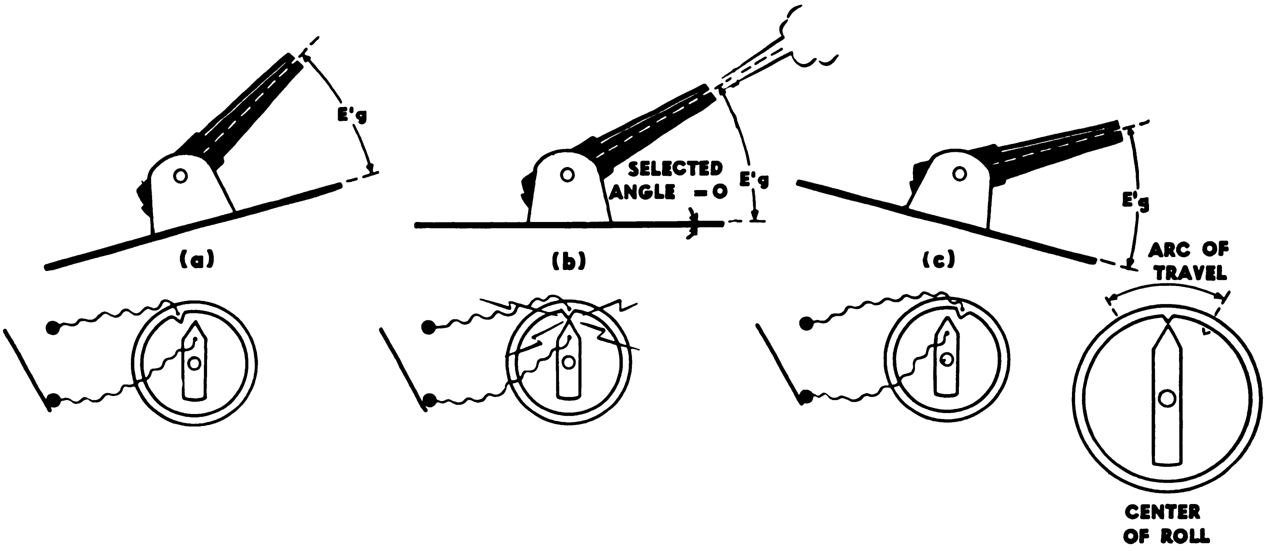


FIGURE 20E4.—Guns move with ship—are fired when deck is horizontal. Contacts close at center of travel.

In the center of the dial face is a small window indicating the setting of the stable-vertical selector switch, located on the right side of the instrument. This window reads CONTINUOUS, LEVEL, or CROSSLEVEL, depending upon the method of operation selected.

The selected level *or* crosslevel dials at the front center of the dial face are set by the hand crank on the front side of the instrument. This dial group shows the value of either *L'j* or *Zhj*, depending upon the method of operation selected. Selected values of level and crosslevel may be received by these dials electrically from the director, if the hand input crank is disengaged.

The level and crosslevel automatic firing contact assemblies referred to in article 20E2 are located at the rear of the dial face. These contacts are used only in intermittent methods of aim. When continuous aim is being used, the automatic contacts are by-passed.

When the guns are fired by selected level (or crosslevel) procedure, the automatic firing key located adjacent to the hand key must be closed when the battery is ready to fire. The actual firing instant will then occur when the automatic contacts are made. The inner contact remains in the position shown in the figure; the outer contact is positioned in accordance with the generated level (or crosslevel) angle plus the additional selected level (or crosslevel) angle, so that it oscillates back and forth with respect to the inner contact as the generated angle changes. The firing

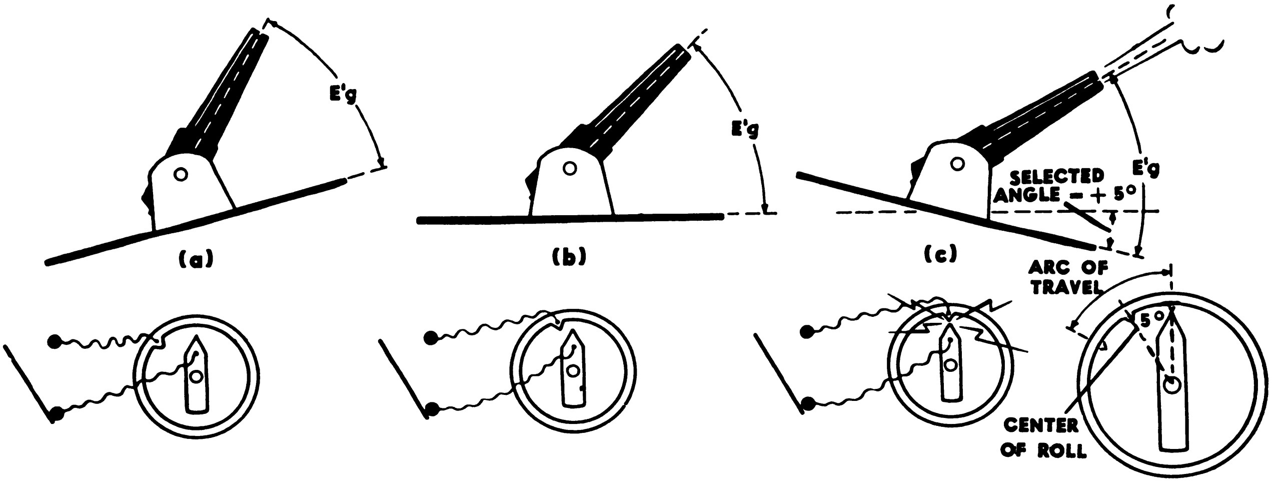


FIGURE 20E5.—Guns move with ship—are fired when selected angle is +5 degrees. Contacts close at 5° from center of roll.

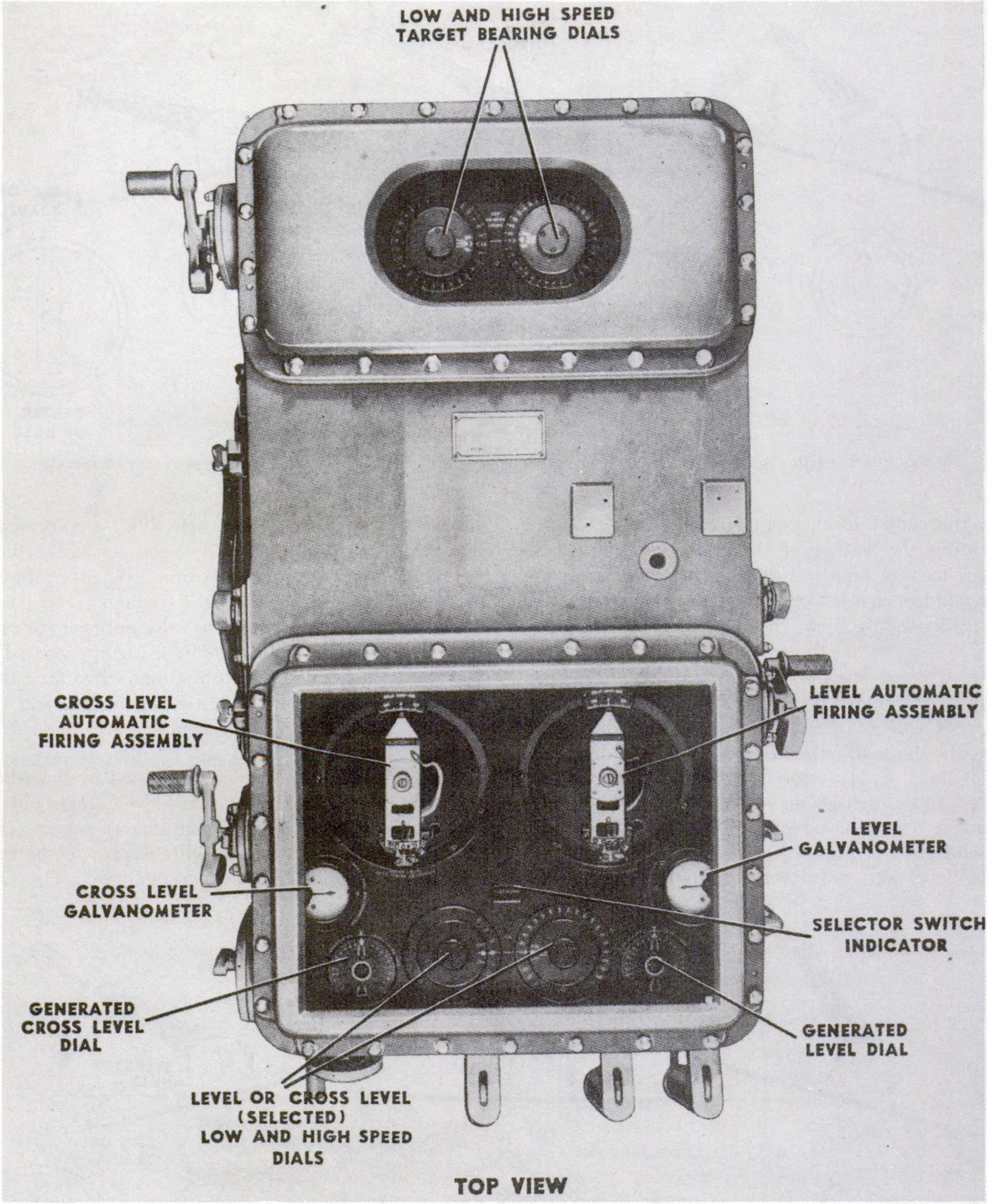

LOW AND HIGH SPEED TARGET BEARING DIALS
CROSS LEVEL AUTOMATIC FIRING ASSEMBLY
LEVEL AUTOMATIC FIRING ASSEMBLY
LEVEL GALVANOMETER
CROSS LEVEL GALVANOMETER
SELECTOR SWITCH INDICATOR
GENERATED CROSS LEVEL DIAL
GENERATED LEVEL DIAL
LEVEL OR CROSS LEVEL (SELECTED) LOW AND HIGH SPEED DIALS
TOP VIEW

FIGURE 20E6. —Stable vertical, top view.

circuit is completed momentarily when the outer contact sweeps past the inner one, thus firing the battery automatically when the selected and generated values are equal.

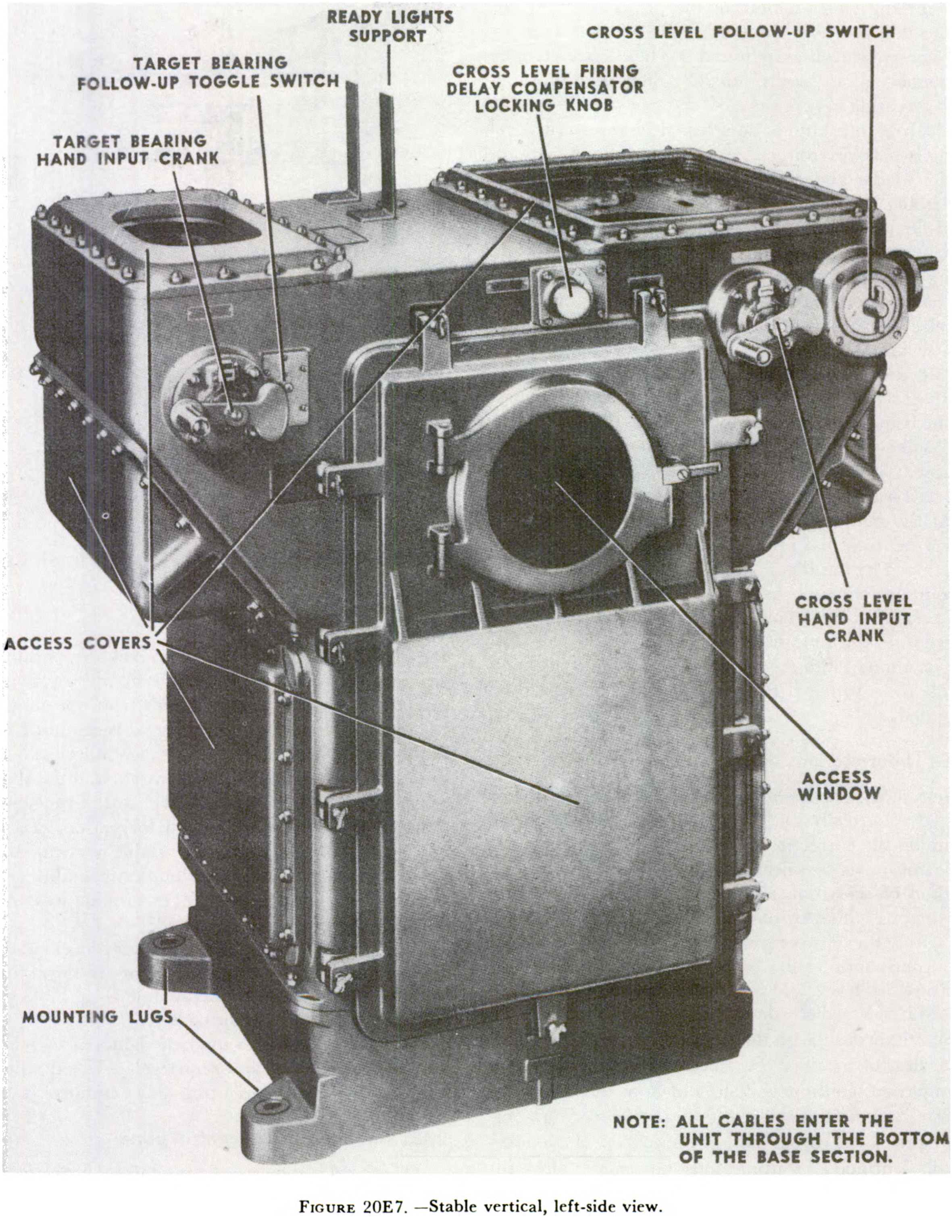

READY LIGHTS SUPPORT
CROSS LEVEL FOLLOW-UP SWITCH
TARGET BEARING FOLLOW-UP TOGGLE SWITCH
CROSS LEVEL FIRING DELAY COMPENSATOR LOCKING KNOB
TARGET BEARING HAND INPUT CRANK
CROSS LEVEL HAND INPUT CRANK
ACCESS COVERS
ACCESS WINDOW
MOUNTING LUGS
NOTE: ALL CABLES ENTER THE UNIT THROUGH THE BOTTOM OF THE BASE SECTION.

FIGURE 20E7. —Stable vertical, left-side view.

The stable vertical contains a firing mechanism consisting of contacts and a firing delay compensator, so arranged that the firing time is advanced to compensate for the ejection time of the projectile, thus ensuring that it leaves the gun at the selected value of level or crosslevel, as required. These contacts may be connected, at the fire control switchboard, in series with the firing keys in the aloft director or at the stable vertical so that automatic selected level or crosslevel firing is possible from either of these stations. In addition to the above-mentioned automatic firing key, the stable vertical has a hand key which is normally used for continuous fire. In this type of fire, during which the guns are constantly stabilized, the hand firing key is part of the series firing circuit, and a selector switch shorts out the automatic firing contacts used in selected fire.

The hand firing key may also be used in selected fire, should the automatic firing mechanism become inoperative. The key is closed when the index marks of the firing contacts coincide.

A salvo-signal key is located at the front of the instrument and is used in conjunction with either firing key as a warning that a salvo is about to be fired.

At the rear top of the instrument can be seen the target bearing dial group. Normally, these dials are positioned by the *B′r′* signal from the director through automatic follow-up action. Under these conditions the target-bearing hand crank (fig. 20E7) is disengaged. If the automatic follow-up should fail, *B′r′* can be entered into the machine by engaging the hand crank and turning it to keep the target bearing dials matched.

20E4. Interrelationships

Selected or continuous level and crosslevel are transmitted electrically to the rangekeeper for computing trunnion-tilt corrections. Whether the transmissions are continuous or selected depends upon the aiming method of operation employed. In continuous aim, continuous values of both quantities are transmitted. In selected-level operation, a selected value of level and continuous values of crosslevel are transmitted. Continuous level and selected crosslevel are transmitted in selected crosslevel.

Simultaneously with the electrical transmissions, and regardless of whether intermittent or continuous aim is employed, continuous values of both quantities are transmitted mechanically to the rangekeeper for computing deck-tilt correction (*jB′r′*). Were these additional continuous transmissions not made, deck-tilt correction would not be practicable in selected level or selected crosslevel.

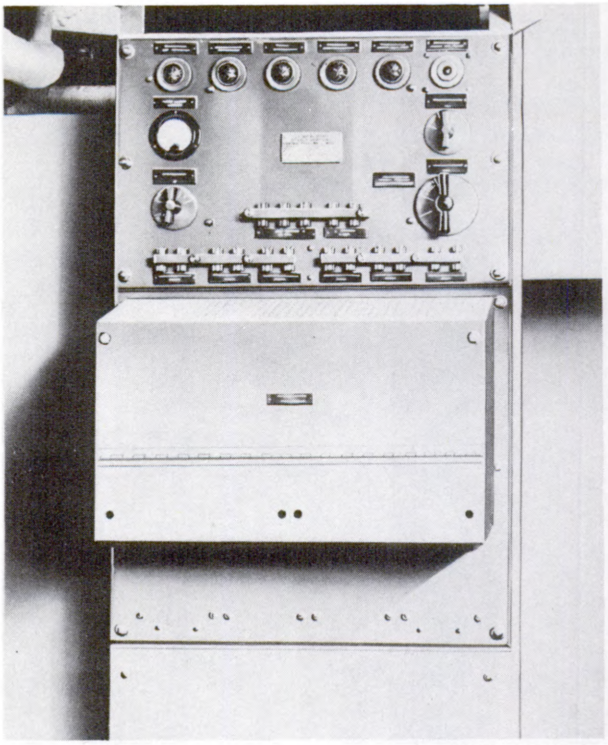


FIGURE 20E8.—The stable-vertical Control Panel Mark 10 located in Plot.

Continuous level may be transmitted electrically to the aloft directors for follow-the-pointer operation by the director, thus permitting level operation in the director in the event the pointer's telescope cannot be used. This continuous-level signal is also used in the aloft directors to stabilize the rangefinders and radar antennae. A *selector drive* is installed in the shafting which carries level and crosslevel to the rangekeeper. When a director is being used for search, and is receiving stabilization from the stable vertical, the selector drives are used to uncouple the stable vertical from the idle rangekeeper. Thus undue wear on the rangekeeper mechanism is avoided.

In case of failure of the level or crosslevel automatic follow-ups, or both, selected level or crosslevel may be maintained by using the hand follow-ups, the galvanometers, and the hand firing key.

Dials are provided to indicate values of target bearing, measured level and crosslevel, selected values of level or crosslevel, and firing-delay compensation.

20E5. Stable-vertical control panel

This panel is shown in figure 20E8. It contains the various switches, fuses, signal lights, and other apparatus necessary for the control of the stable vertical. The stable vertical panel also contains the switches

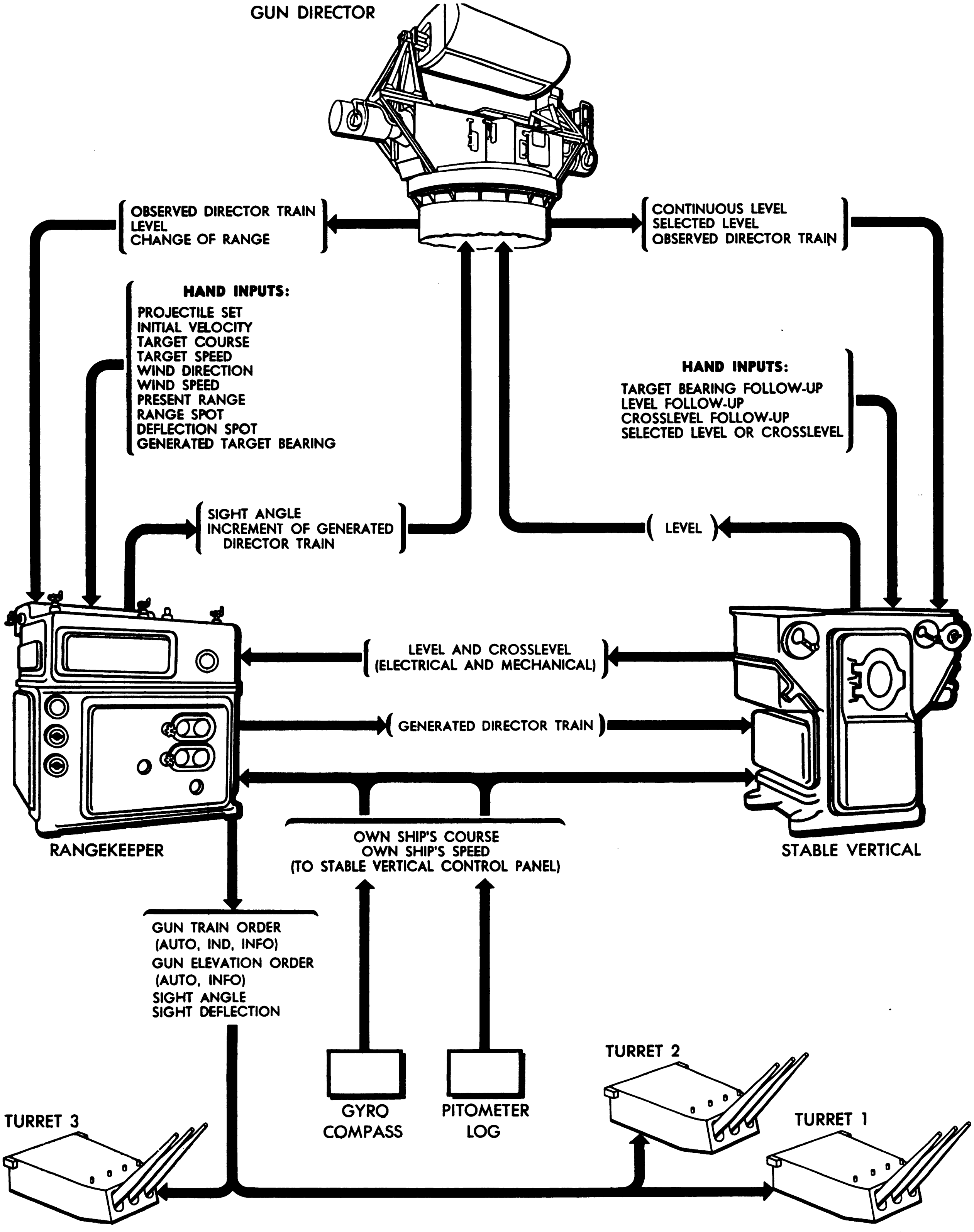


Figure 20E9. —The inputs and outputs of the rangekeeper and stable vertical.

operating the mercury cut-out valve which prevents malfunctioning of the gyro during violent maneuvers of own ship. These switches require synchro inputs of own-ship speed and course for their operation.

Inputs and outputs of the stable vertical and control panel are shown in figure 20E9.

20E6. Rangekeeper Mark 8

The rangekeeper includes most of the controlling, computing, and transmitting fire control mechanisms for the battery. The instrument is a combined rangekeeper, bearing keeper, predictor, deck-tilt corrector, trunnion-tilt corrector, and graphic plotter. Given the hand and automatic inputs listed below, the instrument will compute, indicate, and transmit electrically the information necessary to point the guns and set the sights continuously, and to train the directors and radar antennas continuously on the target. Outputs include the necessary corrections for drift, for wind, for variation in initial velocity, for relative movement of ship and target, for tilt of the gun trunnions from a horizontal plane (trunnion tilt) and for inclination of the director roller path from a horizontal plane (deck tilt). A time-of-flight signal mechanism, which electrically actuates local and distant buzzers indicating the fall of salvos, is included. The graphic plotter automatically plots ranges, sight deflection and time, and the magnitude and time of application of range and deflection corrections. The rangekeeper is equipped with synchro transmitters and receivers, which are used for all electrical inputs and outputs, except for those received by signal lights and those transmitted to lights or buzzers.

1. *Inputs.* Inputs are introduced manually by knobs, and automatically by mechanical and electrical transmission. Some inputs are used to set up the fire control problem, while others are concerned with the transmission of quantities and signals. Of these inputs, the following are used to set up the fire control problem:

Hand Inputs

a. Powder charge and projectile.
b. Initial velocity.
c. Target course.
d. Target speed.
e. Wind direction.
f. Wind speed.
g. Ship course.
h. Ship speed.
i. Present range.
j. Generated target bearing.
k. Observed director train.
l. Deflection correction (spot).
m. Range correction (spot).
n. Time.
o. Level.
p. Crosslevel.

Some of the hand inputs listed above are for emergency use when certain automatic inputs or motors in the instrument are inoperative. Items g, h, j, i, k, n, o, and p are set in by hand only when the corresponding electrical input fails. Items bb and cc below are used only when the electrical follow-up of sight deflection or sight angle, respectively, is inoperative. In the event of failure of the time motor, item ee below is used to drive the mechanism normally driven by that motor.

Mechanical Inputs

q. Level (continuous).
r. Crosslevel (continuous).

Continuous values of level and crosslevel, items q and r, are transmitted mechanically from the stable vertical to the rangekeeper, where they are used to drive mechanisms in the deck-tilt computer.

Electrical (Synchro) Inputs

s. Ship course.
t. Ship speed.
u. Observed director train (automatic).
v. Observed director train (indicating).
w. Range.
x. Level.
y. Crosslevel.

Ship course, observed director train (automatic), level, crosslevel, and range are each received by a pair of synchro receivers equipped with a follow-up device. The latter drives different parts of the mechanism in accordance with the value of the quantity controlling it. Ship speed is similarly received by a single synchro receiver. Observed director train (indicating) is received by a pair of synchro receivers which drive indicating dials only. These dials are used for the introduction of observed director train by hand. Similar dials are driven by the level and crosslevel synchro receivers, in addition to their function of controlling follow-ups.

Additional inputs used only to transmit quantities or signals are:

Hand Inputs

aa. Selected train.
bb. Sight deflection.
cc. Sight angle.
dd. Range-scale shift.
ee. Manual power.
ff. Time of flight (setting of signal mechanism).

Electric (Other Than Synchro) Inputs

gg. Range-mark signal.
hh. Director-ready signal.

A director-ready signal, which indicates that the director is on the target in train, is received and indicated at the rangekeeper by two sets of signal lights. Range-mark signals received from the radar equipment actuate mechanisms in the graphic plotter which plot values of the radar range.

2. *Outputs.* Outputs transmitted electrically are as follows:

a. Gun train order (automatic).
b. Gun train order (indicating).
c. Gun elevation order (automatic).
d. Gun elevation order (indicating).
e. Sight deflection.
f. Sight angle.
g. Increment of generated director train.
h. Generated director train.
i. Time-of-flight signal.
j. Rangekeeper signal to rangefinders.
k. Plot-ready signal.
l. Generated change of present range.

Outputs *a* to *h* inclusive are transmitted by synchro transmitters. Outputs *i* and *j* operate buzzers at distant stations, while *k* controls signal lamps at distant stations. Increments of generated director train are transmitted to the aloft controlling director, where it enables the director sights to be trained automatically. As an auxiliary method of control, generated director train can be substituted in the rangekeeper and stable vertical for observed director train, in case the target is obscured or the transmission from the exposed director is temporarily interrupted. Gun train order (automatic) and gun elevation order (automatic) are transmitted to the turrets for automatic gun laying. Gun train order (indicating), gun elevation order (indicating), sight deflection, and sight angle are transmitted to the respective indicating instruments in the turrets and at other stations. There are no mechanical outputs.

One of the important functions of the rangekeeper is the generation and transmission of increments of generated director train. The quantity, as initially computed in the rangekeeper, is based on electrical inputs of own-ship speed and course, and estimates of target speed and course set in by the operator. Own-ship quantities are accurately measured, but the target estimates may be in error. As the director is trained automatically in response to the generated signal, the director trainer observes the target by means of his telescope or radar indicator. If it is seen that the director tends to drift off the target, the trainer, by means of his handwheels, adds the motion necessary to keep it on. Remote control of such corrections is also possible; the rangekeeper operator in Plot is provided with a separate train transmitter with which he can correct director train in accordance with his radar scope indications. A constant comparison of generated and observed director train is presented to the rangekeeper operator on dials in the rangekeeper. With this information available, the rangekeeper operator needs only to be assured that the director is on the target before adjusting the target estimates. The *on target* signal is given by the director trainer by means of a signal contact maker provided in one of his handwheels.

3. *Generated director train.* This quantity is an initial setting of director train plus the summation of increments of generated director train mentioned in the preceding paragraph. It is, therefore, the computed angle between the center line of own ship and the director line of sight measured in the plane of the deck.

Generated director train is transmitted to the train designator in the controlling director for follow-the-pointer operation by the director trainer. This use enables the director trainer to stay on the target in local power (or manual) operation, should the target become temporarily obscured. Lack of agreement between the generated and observed quantities is indicative of erroneous estimates of target movement used in the rangekeeper solution. It is emphasized that generated director train is *not* used to train the director in automatic operation.

4. *Range.* As originally designed, the rangekeeper computes generated present range and advance range, which may be read on counters on the face of the instrument. Generated present range is the sum of initial measured range between own ship and target, computed change of range in a given time interval due to relative movements of own ship and target, and any range corrections that may have been applied. As previously stated, advance range, used for sight-angle computation, is the sum of generated present range, computed range predictions, and ballistic corrections. Both quantities (generated present range and advance range) are employed solely in the rangekeeper; they are not transmitted outside the instrument.

Generated change of present range is transmitted to the radar control console in the plotting room, and observed range is entered into the rangekeeper solution automatically. If the rangekeeper solution is incorrect, the radar operator at the control console may superimpose corrections on the transmitted signals, thus causing rotation of a solution-indicator dial on the rangekeeper. The rangekeeper operator then corrects the set-up by modifying the inputs of target course and speed, in order that the radar equipment may track the target correctly. This method of ranging is known as *aided ranging*.

5. *Corrections.* The rangekeeper also computes trunnion-tilt and deck-tilt corrections, but does not transmit these quantities.

a. *Trunnion-tilt correction.* The computations made by the trunnion-tilt corrector are based upon measured values of level and crosslevel received from the stable vertical and computed values of sight angle and sight deflection. The computed corrections are applied in the rangekeeper to sight angle and sight deflection before addition of these quantities to level and director train respectively, to form gun elevation and gun train orders.

b. *Deck tilt correction.* This quantity ($jB'r'$) is computed from observed director train received from the controlling director, and values of level and crosslevel received from the stable vertical. It is added to director train measured in the deck plane to obtain relative target bearing in the horizontal plane. This is needed, since the rangekeeper computes its solution in the horizontal. It can also be used to convert a value computed in the horizontal to one in the deck plane, as, for instance, increments of generated director train.

6. *Graphic plotter.* The graphic plotter is mounted on, and usually functions with, the rangekeeper. As originally designed, it records observed ranges from several remote stations, direction and time of application of deflection and range spots, values of generated and advance range computed by the rangekeeper, and the value of advance range existing when the time-of-flight button is pushed; and it plots continuously a trace of sight deflection computed in the rangekeeper.

After completion of current alterations, the graphic plotter will no longer receive and plot values of observed range from the several rangefinder stations, but instead will plot only values of observed range from the radar equipment. This will be entered into the rangekeeper solution automatically and plotted at the same time. Plotting of other quantities enumerated above will be carried out as heretofore.

Inputs and outputs. Inputs and outputs of the rangekeeper are shown in figure 20E9.

20E7. Analysis of rangekeeper set-up

Since the rangekeeper solution of the problem is based on inputs, of which A, target angle, and S, target speed, are estimated, it is obvious that the values of $E'g$ and $B'gr$, as solved by the rangekeeper, will be correct only if the estimated inputs are correct.

The analyzing feature of the rangekeeper provides the means for correcting the errors in setting target course and target speed. This operation is known as *rate control* and is defined as "the solution for correct target course and speed by causing the generated range and bearing rates to agree with the observed values." Note that only *one* combination of target course and speed will cause *both* range and bearing rates to agree, and that this combination is the solution.

The amount and direction of change of target speed and target angle to effect such agreement varies for different conditions of target motion. Consideration of the three very general conditions below will clarify this:

1. *Target angle 000° or 180°.* In this case the target is moving in the LOS, and $Yt=S$ and $Xt=0$. Therefore a change in target speed will directly affect generated range rate but will have no effect on bearing rate. Changing Ct will introduce a plus or minus Xt, with corresponding change in bearing rate. (Unless the change in Ct is large, the effect on dR will be very small.) Thus, in this case, S is the dominant element in the range rate and Ct is the dominant element in the bearing rate.
2. *Target angle 090° or 270°.* In this case the target is moving across the LOS, and $Xt=S$ and $Yt=0$. Therefore a change in target speed will directly affect the generated bearing rate but will have no effect on range rate. Changing Ct will introduce a plus or minus Yt, with corresponding change in range rate. (Unless the change in Ct is large, the effect on range rate will be very small.) Thus, in this case, Ct is the dominant element in the range rate and S is the dominant element in the bearing rate.
3. *Target angle 045°, 135°, 225°, or 315°.* In this case a change in S will affect, equally, range and bearing rates, since the sine and cosine of 45° are the same. A small change in Ct will affect range and bearing rates approximately the same. Therefore, a change in either rate unaccompanied by a change in the other rate, can, in this situation, result only from simultaneous alterations of both target course and target speed.

Since target angles of 000°, 090°, 180°, or 270° are rarely encountered, the last case (target angle 045°, 135°, 225°, or 315°) is more typical of actual conditions that are apt to be encountered. Consideration will now be given to rate control for a set-up in which the target angle lies between the values covered in the general cases described above.

Suppose that a situation exists as shown in figure 20E10. At position 1, own ship is on course Co at speed So, and its vector is correctly set in the rangekeeper. The target is actually on course Ct at speed S, but because of an error in estimating the target motion, its vector is set in the instrument as though it were on course Ct' at speed S'. The respective target angles are A_1 and A'_1 and the range component of the vector S' is equal to the range component of S. Under these conditions, dR computed by the rangekeeper agrees with the actual value of dR. It is apparent that there are many combinations of A'_1, Ct', and S' which will have the same range component.

After an interval of time has elapsed, the two ships will have advanced, along their actual courses, distances proportional to their actual speeds, and will be at position 2. The actual target vector is still S: the target vector set in the instrument is still S'. The target angles between S and the LOS and S' and the LOS will have changed by the same amount that Br has changed, and the line components will be Yt_2 and Yt'_2. Evidently the computed value of dR will no longer agree with the actual value of dR; cR will be out of agreement with R, and it will be necessary to adjust the values of target angle and target speed set on the instrument.

At position 1, computed dR was correct. But computed $RdBs$ was in error by the difference between Xt_1 and Xt'_1. The only set-up of the rangekeeper which would produce the correct values of $RdBs$ and dR at the same time is that in which A and S are used for the settings. Had both range and bearing rates been correctly set on the instrument at position 1, both of these rates would be correct at position 2, and cR would be in agreement with R. Thus, if the correct target track is to be established, the operator must adjust both rates.

Since target bearing is generated in a manner similar to the generation of range, a disagreement between generated bearing (cBr) and Br will indicate that computed $RdBs$ is wrong. (See figure 20E12.)

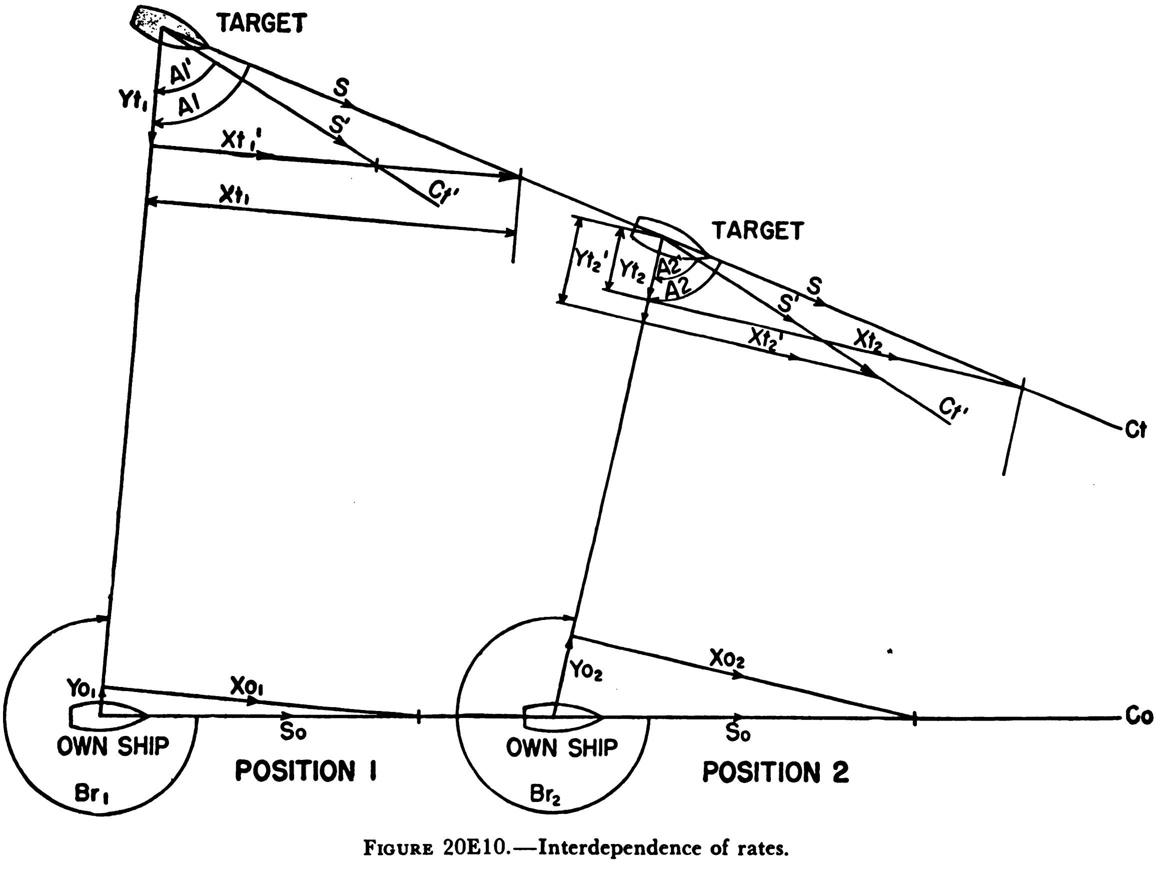


FIGURE 20E10.—Interdependence of rates.

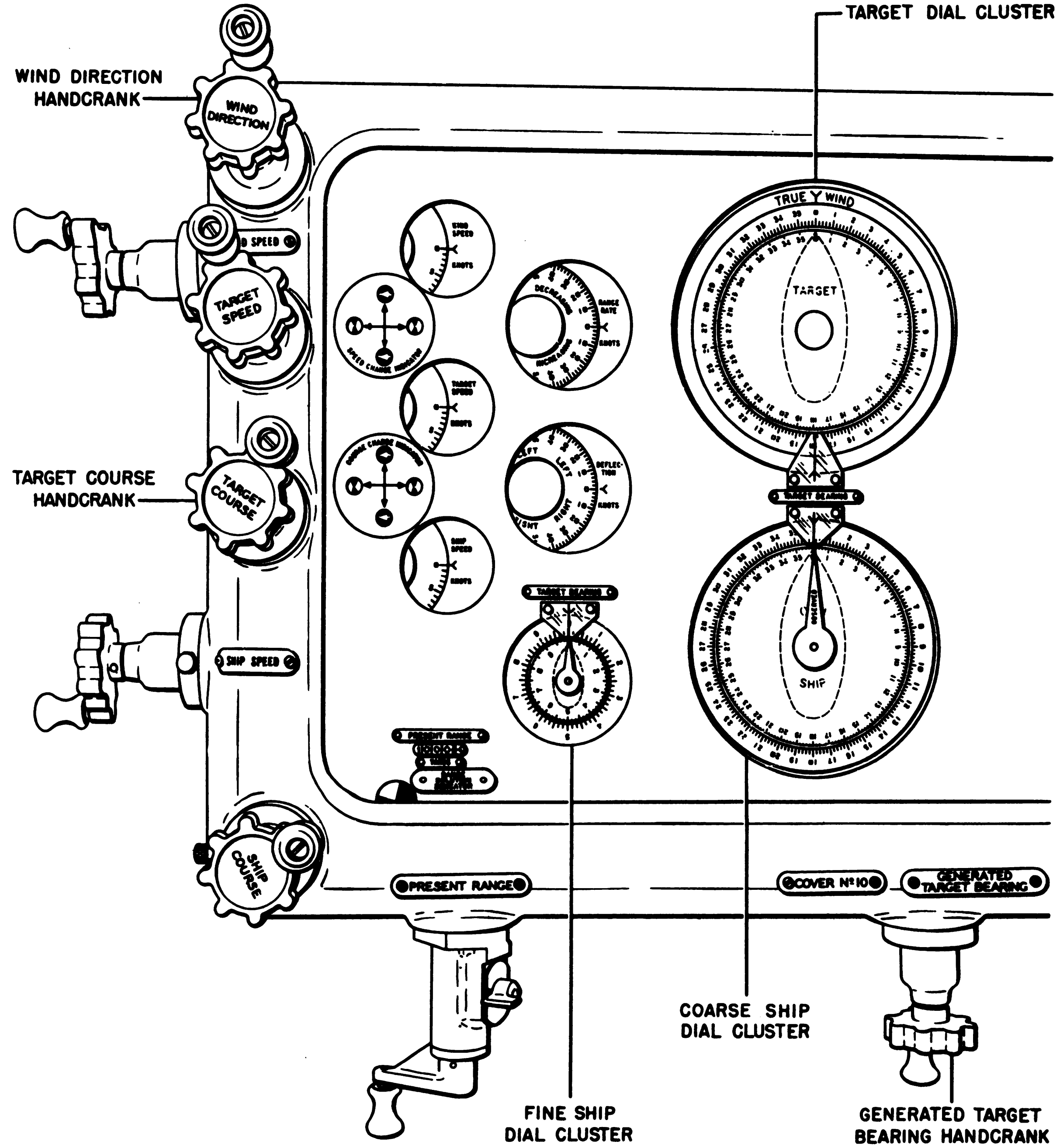


FIGURE 20E11.—Own-ship and target dial group of Rangekeeper Mark 8, showing control cranks.

When *RdBs* is wrong and *dR* is correct, as at position 1 in the diagram, the operator can adjust *A* and *S* to correct *RdBs* without changing *dR*, by maintaining the dial reading of *dR* at the value indicated before the adjustment is made. Similarly, *dR* can be corrected without changing *RdBs* if conditions require such an adjustment.

The analytical aspect of rate control has been considered thus far. The following is a brief discussion of the manner in which rate control is actually accomplished by the rangekeeper operator.

Referring to figure 20E12, the picture shown on the target and own-ship dials is merely an indication of the vectors for a typical example.

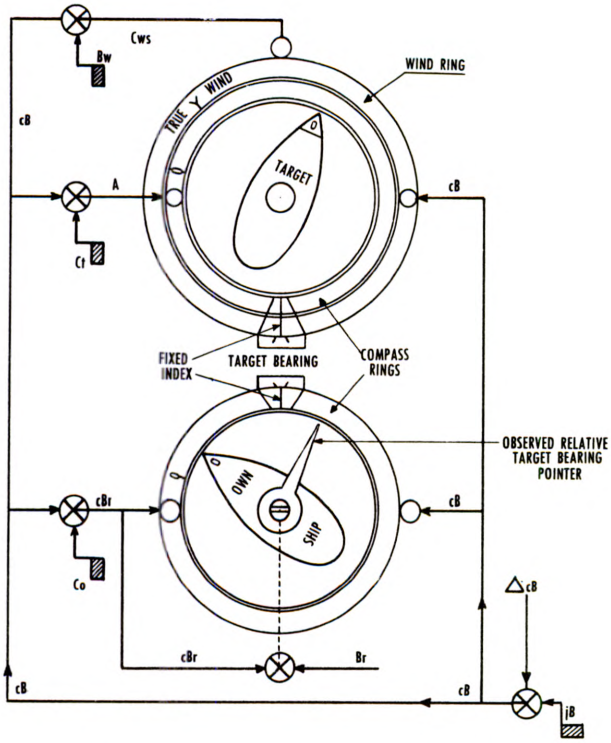


FIGURE 20E12.—Bearing setting diagram.

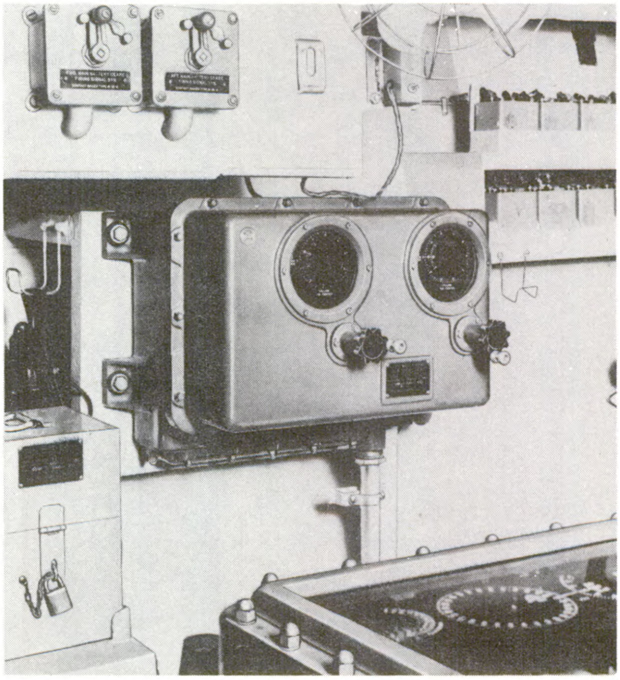


FIGURE 20E13.—Gun train order relay transmitter.

From the figure, it can be seen that the observed bearing as given by the pointer is farther to the right than the generated value which is read opposite the fixed index above own-ship dial. This indicates that the generated and observed bearing rates do not agree. If at the same time the generated range rate (see range-rate dial, fig. 20E11) is compared with the rate given by the graphic plotter, the whole picture becomes evident.

Let us assume that the generated range rate is increasing at 15 knots, while observed range rate is increasing at 10 knots. These facts indicate that the generated *Xt* component is too small and the *Yt* component is too large. If the operator changes target course to the right, the *Xt* component will be increased and the *Yt* component decreased, both of which are desired. If the operator increases target speed, *Xt* will be increased; but *Yt*, which is already too large, will be further increased. In the situation shown, target course is the dominant element and should be changed first. Before making a course change, however, the operator should ensure that present range (as shown in window at the lower left-hand corner of the rangekeeper face) is correct, if hand input is being used, and that the observed bearing pointer is reset opposite the fixed index.

In resetting bearing, reference to figure 20E12 will show that all dials will turn together when *jB* is changed, and thus the present setting of target angle will be thrown off. For instance, after the observed-bearing pointer is reset on the fixed index, target angle will read roughly 180°, instead of 160° as it does in the figure. By use of the target-course crank it must be returned to its original value, 160°, and then the additional corrective change to the right, to about 140°, should be made. This change should bring the generated range rate closer to the observed graphic-plotter rate.

The operator observes the set-up as the rangekeeper continues to generate the solution. He watches the bearing pointer to see if it continues to drift off in the same direction, stops on the fixed index, or reverses its motion. He continues to compare observed and generated range rates to determine if additional corrections are necessary. In some installations course and speed indicators are provided to assist the computer operator in visualizing the rate control situation.

Resetting the present-range dial to the correct observed value was required on earlier models of the rangekeeper, but recent models have a two-position shift lever on the present-range crank, with HAND and AUTOMATIC settings. When in AUTOMATIC, range from the rangefinders or radar is fed in automatically, so that the dial remains correct. Resetting is required only in HAND position.

The above example of rate control for the particular

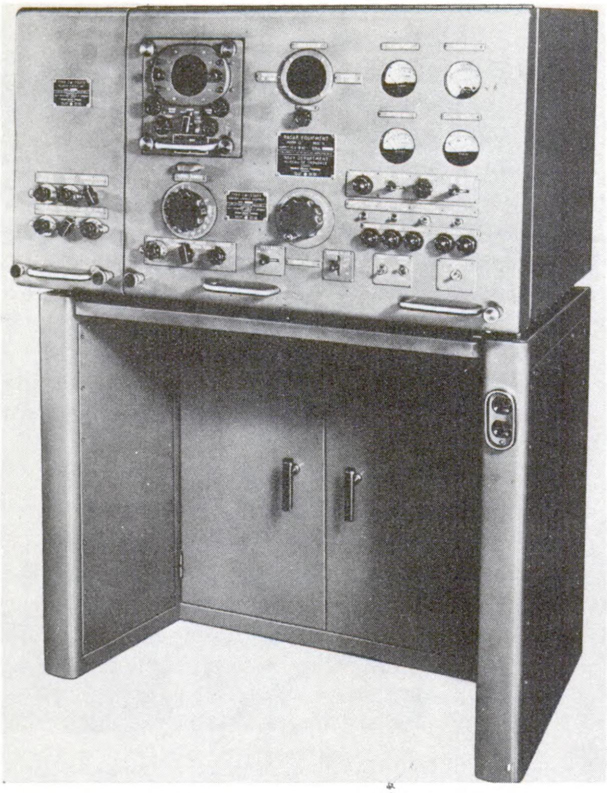


FIGURE 20E14.—Radar console used for Radar Equipment Mark 13 Mod 0.

problem set-up shown is given to indicate the type of reasoning a rangekeeper operator must develop. It should be stressed that there is no hard and fast rule for the amount of change to make in *Ct* and *S* to obtain the proper solution. Long hours of practice in tracking actual targets alone will provide the experience required of an efficient rangekeeper operator.

20E8. Gun train order relay transmitter

Additional equipment in the plotting room includes the gun train order relay transmitter shown in figure 20E13, which relays gun train orders (for information) from the rangekeeper or aloft directors to the multiple turret train indicators. The relay transmitter prevents the heavy load on this circuit from adversely affecting the accuracy of transmission of gun train order to the guns. The instrument receives gun train order (indicating) from either the rangekeeper or the director (or in divided fire from both) and relays this order to the multiple turret train indicators. Normally this operation is automatic, but the instrument is provided with hand cranks and follow-the-pointer dials for emergency use. The relay transmitter can be used only when the main-battery switchboard is in operation.

In some installations the rangekeeper is equipped with a one-speed synchro transmitter for turret train information in addition to the usual two sets of synchro transmitters for gun train order (automatic) and gun train order (indicating). In such installations no separate gun train order relay transmitter is required nor provided.

20E9. Radar equipment

The radar equipment is used to measure range, radar range being generally preferred to optical range. Range measurement is controlled by the radar-range operator in the plotting room, who operates the radar-range unit. From this unit range is transmitted to range receivers in the director, in the plotting room, and in fire control and other stations. The radar equipment may also be used for training the director under conditions of poor visibility, since it has a narrow, well-defined beam and comparatively high accuracy in bearing discrimination. The director trainer has a radar indicator at his station in the director, to guide him in getting on and tracking the target by radar. Observed director train is measured and transmitted in exactly the same way when the radar equipment is used, as when the director is following the target by optical means.

Units of the radar equipment used with the antenna mounted on the forward director are located in the plotting room, as shown in figure 20E1. Older ships are supplied with Radar Equipment Mark 8 Mod 3, later ones with Mark 13 Mod 0.

Operation of Radar Equipment Mark 13 is controlled by the power, range-track, long-range, and receiver controls, located on the front of the control console. A range and train indicator is provided to enable the operator to slew onto the target and then track in range at the console. When the control key is placed in manual ranging (LOC) position, ranging is controlled by the range-track crank at the console.

Aided ranging is made possible by placing the control key in REM position. By appropriate switching on the main-battery switchboard, the rangekeeper's generated change-of-range transmitter sends its signal through the console's range-control transmitter for monitoring by the radar operator. The corrected signals then go to the radar amplifier cabinet.

At the amplifier cabinet, range control is received from the console or from a director. The range unit and drive assembly measures the range between the antenna and a target. It transmits range to the range repeater on the console, to the rangekeeper, and to synchro range indicators throughout the ship. In an emergency, manual ranging can be done at the amplifier cabinet.

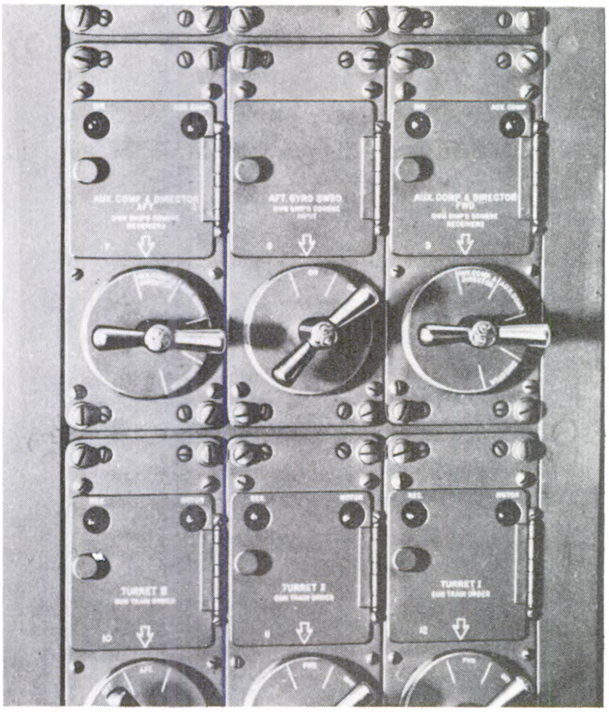


FIGURE 20E15.—Close-up of typical rotary switches.

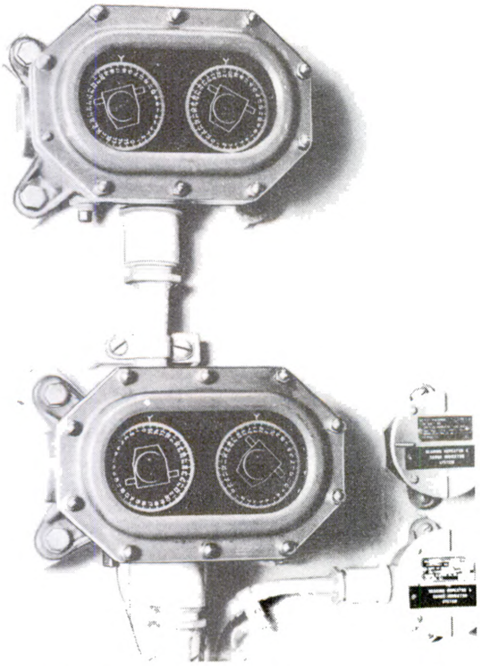


FIGURE 20E16.—Director train indicators.

20E10. Main-battery switchboard

The plotting-room fire control switchboard is shown in figure 20E2. The board consists of five panels of type-J rotary switches, a fuse panel, and a snap-switch panel for the interior communications circuits. Figure 20E15 shows typical rotary-switch units.

The switchboard serves as a central point at which the synchro receivers and synchro transmitters in the various instruments and equipment comprising the fire control system can be energized and connected together as required for operation in different methods of fire control. Selections of signals to and from various elements of the system can be made, and substitute and alternate circuits can be set up in the event of casualties to some part of the system.

20E11. Miscellaneous equipment

Multiple turret train indicator. The plotting room contains one MTTI (see fig. 20E1), which shows the train of each of the three turrets and the difference between modified turret train response and gun train order. This instrument is the same as those used in the fire control stations.

Bearing indicator. This device (see fig. 20E1) indicates true target bearing, relative target bearing, and own-ship course. It is used for information purposes and is the same as those used in the fire control stations.

Dead-Reckoning Tracer Mark 6. This instrument, shown in figure 20E2, is a plotting table with a pencil mechanism for charting own-ship course. North-south and east-west distance components, received from the analyzer of the dead-reckoning system, actuate the motors and mechanisms which drive the pencil carrier to record a graphic plot of the ship's travel and also drive the dials which indicate the latitude and longitude. A clock mechanism is electrically connected to the pencil carrier to record elapsed time on the graphic plot. Any point defined by range and true bearing may be plotted relative to own ship on the plotting board. The equipment is used during shore bombardment operations.

Director train indicators. Two director train indicators, shown in figure 20E16, are mounted on the plotting-room bulkhead. These instruments show the train angle of the forward and after main and secondary battery directors.

Ready lights. The plotting room contains numerous salvo signal lights, turret ready lights, and other signals to provide visual information from other stations.

20E12. Auxiliary main-battery switchboard

In the event of casualties to the main-battery switchboard, gun orders can be routed from the directors to

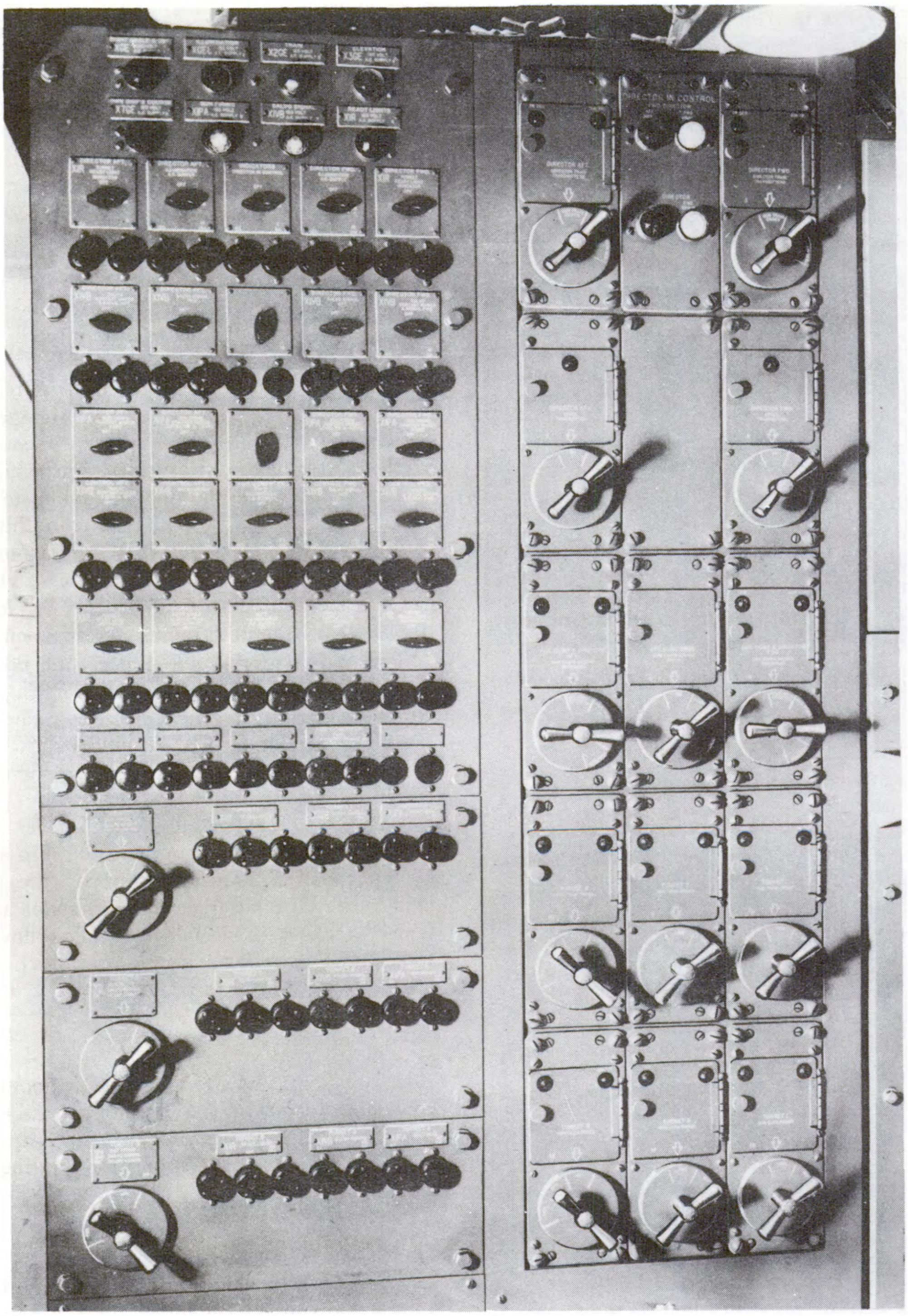


FIGURE 20E17.—The auxiliary main-battery switchboard, located in the after gyro room.

the turrets *via* the auxiliary switchboard. This board is located in the after gyro room and is connected with directors 1 and 2 and with turrets 1 to 3 by cables run in separate wireways widely separated from the primary cables. In order to shift control of the system to the auxiliary main-battery switchboard, switches located at the fire control stations and turrets are shifted from MAIN to AUX position.

The board consists of one switch panel and a snap switch and fuse panel. Indicator lights show the division of battery control between the directors. Type-J selector switches control the routing of gun orders and other data for the fire control installation. Figure 20E17 shows the front of the switchboard.

F. Turret Fire Control Equipment

20F1. General

The fire control equipment installed in the turret is shown in the cut-away view of figure 20F1. Part of the equipment is located on the shelf plate, or upper level of the turret, and the rest on the two decks below.

On the shelf plate at the rear is the turret officer's booth. This space contains the rangefinder and the rangefinder stabilizer, the spotter's periscope, auxiliary computer, multiple turret train indicators, and various switches and indicating lights. Forward, are four sight stations, one on each outboard side of the turret and two between the guns. The right station contains the trainer's periscope and handwheels, and the train indicator. The other three stations contain the periscopes, handwheels, and elevation indicators for the three pointers, one for each gun. At the extreme left is the checker's periscope. The shelf-plate equipment provides the means by which the turret can be operated independently of the rangekeeper and directors. The sights enable the target to be located; the rangefinder measures the range to the target; and the computer solves the fire control problem for *Vs* and *Ds*.

On the pan floor, one deck below the shelf plate, are the elevation receiver-regulators and the elevating-gear A-ends and B-ends. The receiver-regulators control the elevation of the guns (which operate independently in elevation) in response to the gun elevation order (auto and local), and the elevating gears actually move the guns. Also on the pan floor is the training-gear B-end.

On the next lower deck, the electric deck, are the train receiver-regulator, which controls the training of the turret, and the training-gear A-end. Emergency hand cranks for training and elevating the guns manually in the event of power failure are mounted on the shelf plate, in compartments adjacent to the wing guns.

20F2. Rangefinder

The rangefinder passes through the turret officer's booth in back of the beam at the upper right of figure 20F2. Turrets 2 and 3 are equipped with rangefinders of the erect-image stereoscopic type and are capable of measuring ranges from 2,500 to 50,000 yards. The base length is 26 feet 6 inches, and the magnification is 25 diameters. The rangefinder in turret 1 is of the erect-image, coincidence type, with the same base length and magnification.

Sighting through the main eyepiece, the rangefinder operator adjusts the measuring knob to keep the wander mark on the target in the stereoscopic type of rangefinder, or to match the two images in the coincidence type. The operator then presses the switch in the center of the measuring knob, which sends an electrical signal designating the range to the rangekeeper. Range may also be read from the range scale and transmitted by phone (JW circuit) to the rangekeeper operator. Besides the main eyepiece there is a rangefinder trainer's eyepiece, used for locating and centering the target in the main instrument field.

The *rangefinder stand* supports the rangefinder in two saddle bearings, which permit the rangefinder tube to be rotated through 30 degrees. The stand also permits deflection of the rangefinder 5°30′ left or right of the line of the gun bore, to nullify the deflection of the guns from the line of sight.

The rangefinder is stabilized in level—that is, its line of sight is held horizontal as the ship rolls—either by means of a hand lever or by the rangefinder stabilizer. The latter device consists of a gyroscope, which activates an electric-hydraulic follow-up system to keep the rangefinder level. A clutch handle is provided to shift from hand to automatic stabilizing.

20F3. Periscope

Figure 20F2 shows the periscope mounted in the roof of the turret, which serves for general lookout purposes; for picking up targets; for estimating their range, course, and speed; and for spotting the fall of shells.

20F4. Auxiliary computer

The Computer Mark 6 shown in figure 20F3 is a standby instrument intended for use only when the turret is isolated by casualties. It is located at the right side of the turret officer's booth and operates without mechanical or electrical inputs to compute *Vs* and *Ds*. It will not be described here.

Because some of the refinements of calculation found in Rangekeeper Mark 8 are omitted from the design of the auxiliary computer for compactness and to

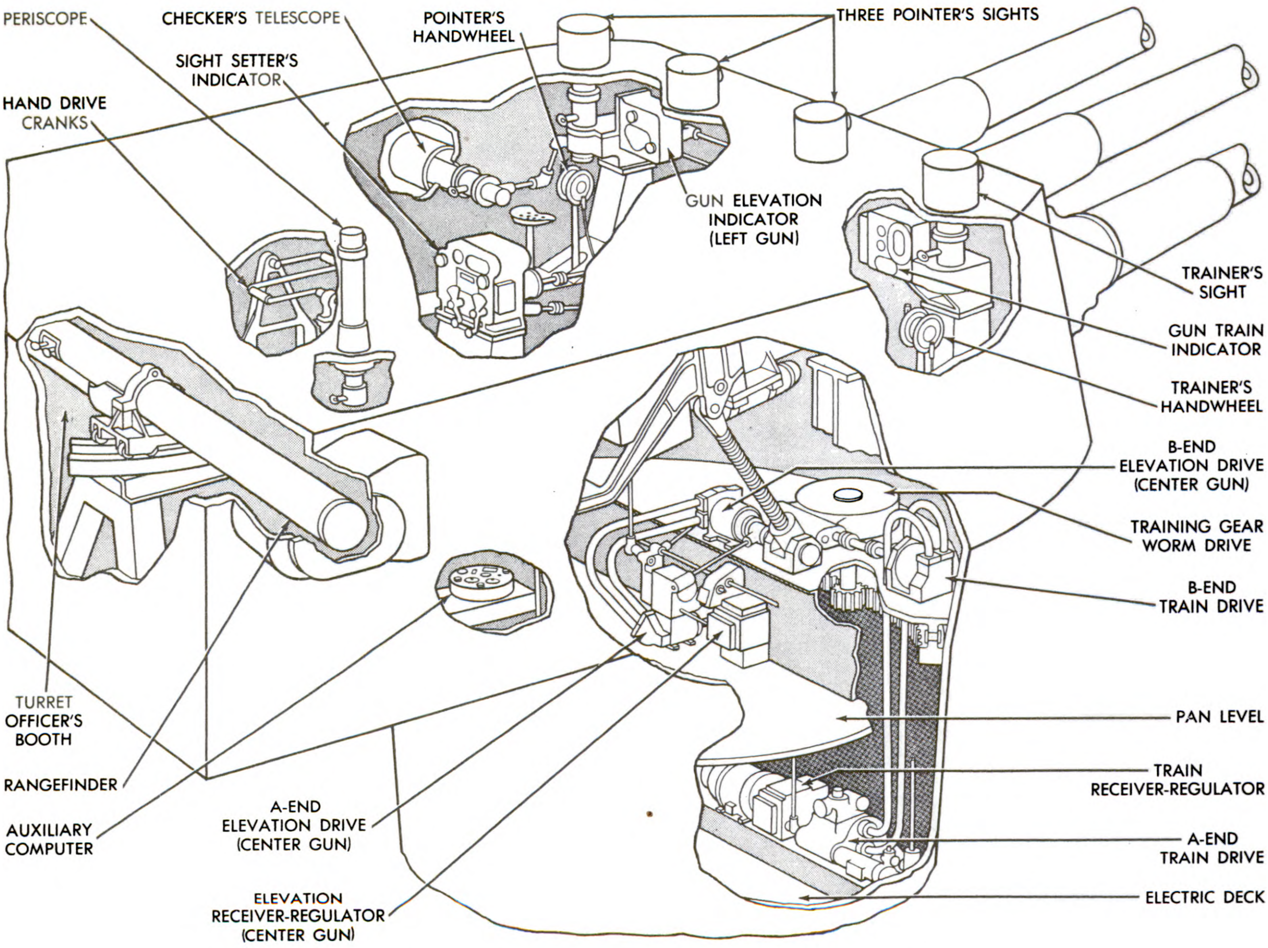


FIGURE 20F1.—Cut-away view of main-battery gun turret.

permit the use of the computer independently of the major control systems, the solution obtained with it is not as accurate as with the more complex instrument.

20F5. Multiple turret train indicator

The turret officers' booth contains an MTTI similar to those in the plotting room and fire control stations. Turrets 1 and 2 each contain a train indicator showing turret train and gun train order for turrets 1 and 2; turret 3 contains an indicator showing such data for own turret only.

20F6. Eight-inch sight

The turrent sight consists of the trainer's, checker's, and the three pointers' periscopes and the shafting which connects them with the sight setter's indicator and the gun attachments. The sights are used to aim the guns in LOCAL, and to check the aim in other methods of gun laying.

As the trainer trains the turret to bring the vertical crossline on the target, and the pointers elevate the guns to bring the horizontal crosslines on the target, the gun bores are deflected both horizontally and vertically from the line of sight according to the sight angle and sight deflection set in by the sight setter.

The line of sight of all the sight telescopes may be deflected 110 mils right or 90 mils left of the gun axis, and the pointers' and checker's telescopes may be elevated 1° above or depressed 41° below this axis. Stops on the foot treadle and hand lever of the trainer's sight permit 18° movement above and below a plane parallel to the roller path of the turret.

As previously mentioned, the turret sight is used primarily for positioning the turret guns in local gun laying. However, in those methods of gun laying where the sight is not directly employed, the telescopes are continuously positioned by the combined action of the sight setter and gun elevation response, so that

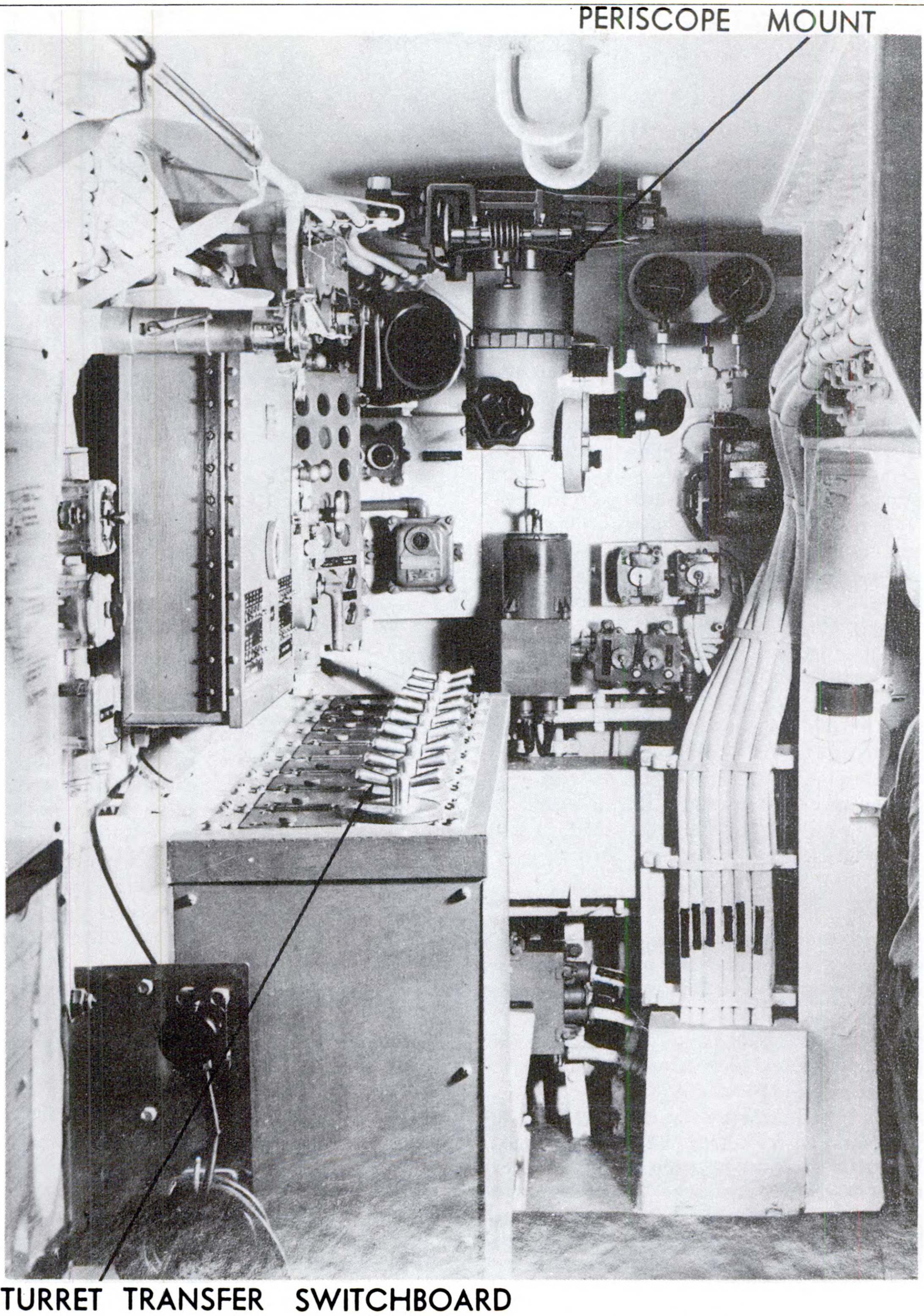


FIGURE 20F2.—Turret officer's booth, looking toward right side of turret.

they may be used for checking purposes, and so that they may be in constant readiness for change-over to local control if necessary.

20F7. Sight setter's indicator

The sight setter's indicator, shown in figure 20F4, is located abaft the center pointer's station in each turret and serves as a range, sight-angle, and sight-deflection indicator. The sight setter's indicator receives two electrical inputs: sight angle and sight deflection. By turning cranks on the front of the instrument to match the outer dial with the inner electrical dials, these quantities are transmitted mechanically to the sights. Sight angle is also transmitted by shafting to the gun elevation indicators and receiver-regulators, where it is used in the erosion-correction mechanisms.

The sight setter's indicator contains a parallax range scale and crank, and a range scale. By turning the parallax-range crank to set in the range read from the range scale, the sight setter transmits parallax range to the train indicator and the train receiver-regulator, where it is used in computing the parallax correction. Since sight angle is a function of range for a given muzzle velocity, it can be converted to range. This is done by the range scale, which is driven according to the sight angle set in the instrument, but which is graduated to read range.

The sight setter's indicator is used to set the sights in all methods of gun laying and of turret drive. In addition, it supplies mechanical inputs of sight angle and parallax range respectively to the elevating and training equipment, for the purposes noted, in both automatic and indicator gun laying.

20F8. Training equipment

The training equipment consists of the trainer's handwheels, the gun train indicator, the train receiver-regulator, the training speed-gear A-end and B-end, and accessory equipment.

The turret is trained by means of the training speed gear controlled by the train receiver-regulator or the trainer's handwheels.

The trainer's handwheels may be connected by means of a clutch to the tilting plate of the training-gear A-end, or to the receiver-regulator. The trainer operates his handwheels either to bring his vertical crossline on the target (in local gun laying) or to match the dials of the gun train indicator (in indicator gun laying).

20F9. Gun train indicator and transmitter

The gun train indicator, shown in figure 20F5, is located at the trainer's station on the right side of the turret. The instrument receives gun train orders on synchro receivers. It is used in indicator gun laying to guide the trainer in operating his handwheels so that these orders are carried out. One synchro receiver operates a zero-reader dial; the other a follow-the-pointer dial. The instrument mechanically receives turret train response from the training gear, and parallax range from the sight setter's indicator. Parallax range and turret train response operate the parallax corrector, which computes the correction for parallax. This correction is introduced into turret train response by means of a differential to produce modified-turret train response, which operates the outer dial of the follow-the-pointer dials, and restores the zero-reader dial to zero. Turret train response is displayed on dials for comparison with the electrical order dials, and is transmitted electrically by synchro transmitters to the MTTI's in various stations in the ship. In automatic gun laying the gun train indicator is not used to control the turret, but still indicates gun train order and modified turret train response, and transmits the latter to the MTTI's.

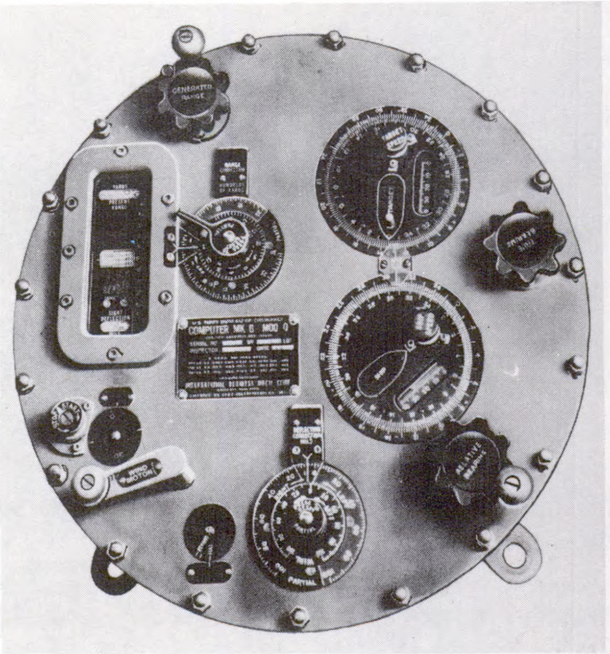


FIGURE 20F3.—The Auxiliary Computer Mark 6 Mod 0, used only in local control.

20F10. Train receiver-regulator

The train receiver-regulator, shown in figure 20F6, is located on the electric deck.

It controls the training gear in accordance with an electric gun train order. The instrument has three inputs: gun train order (received electrically from the plotting room or auxiliary switchboard, or mechanically from the trainer's handwheels, depending on the method of gun laying employed); parallax range, received mechanically from the sight setter's indicator; and turret train response, received mechanically from the training gear. Within the regulator, turret train response is corrected for horizontal parallax and matched with gun train order. The difference between the actual and ordered positions of the turret creates an error signal which is amplified and used to control the training speed gear in such a manner that the turret is automatically trained to the ordered position. The train receiver-regulator operates normally in response to remote or local signals.

20F11. Training speed gear

The turret is trained by the hydraulic training gear, which consists of a motor-driven pump (A-end) and a hydraulic motor (B-end). Part of the gear can be seen in figure 20F6. The hydraulic motor drives a

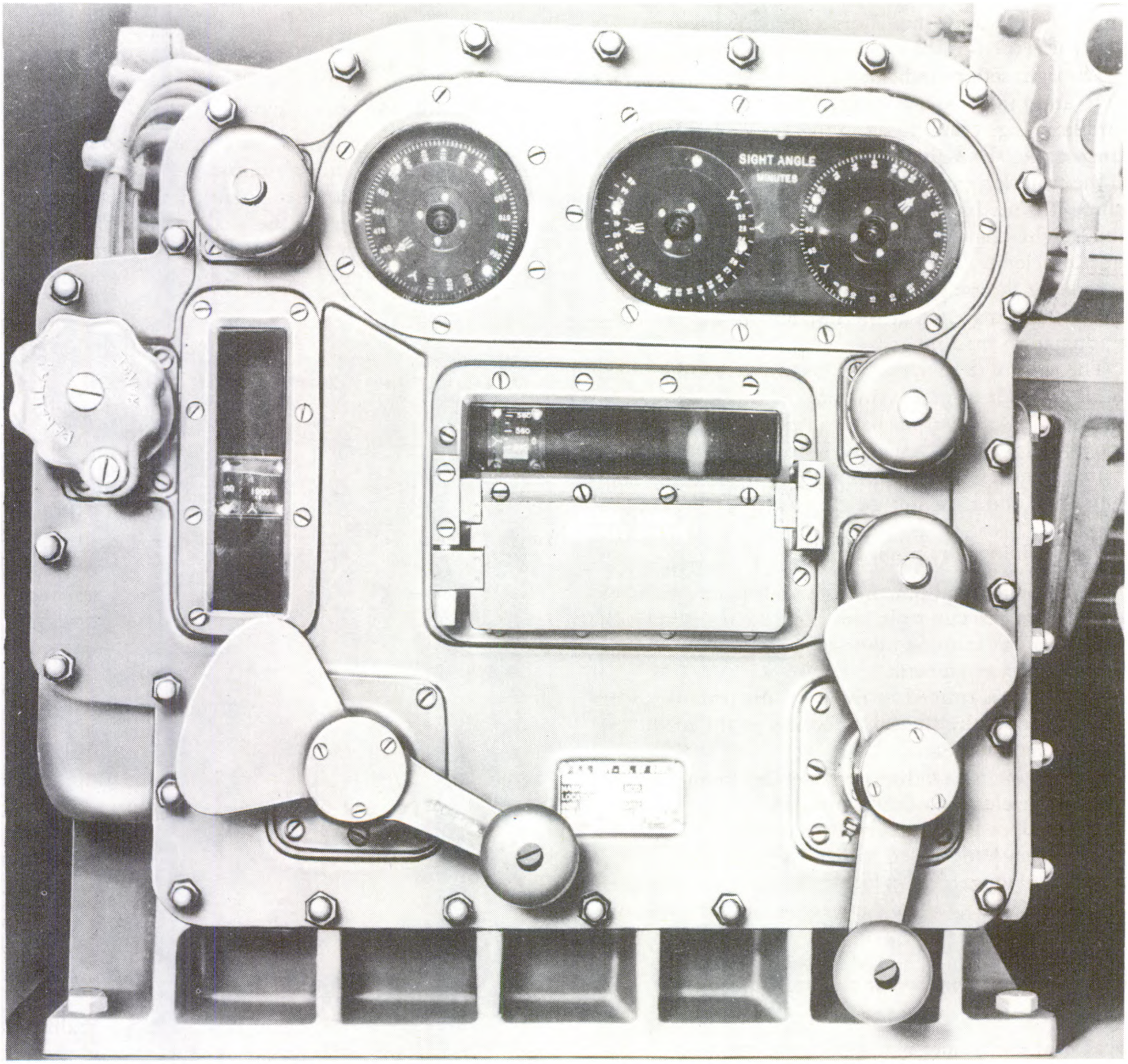


FIGURE 20F4.—Sight setter's indicator.

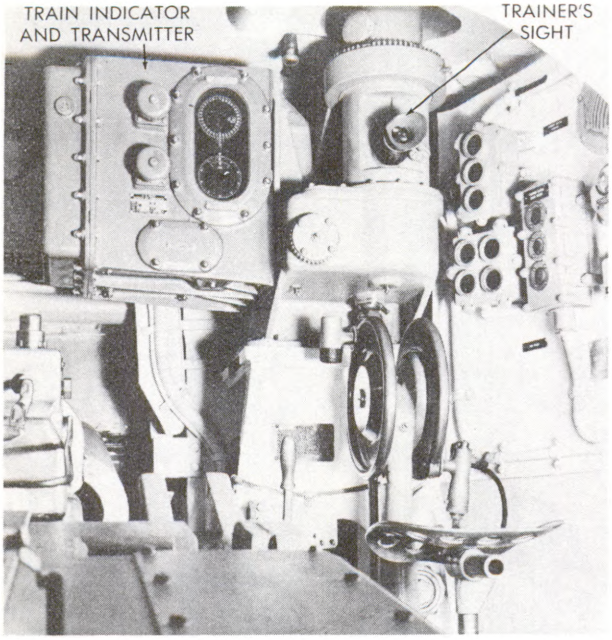


FIGURE 20F5.—Turret trainer's station. The gun train indicator and transmitter is located alongside the trainer's periscope.

pinion which engages with a stationary rack mounted on the barbette. As the pinion rolls around this rack, the turret is carried with it. Speed and direction of rotation depend upon oil flow from the A-end, which in turn is controlled by the train receiver-regulator or mechanical handwheel drive.

In the event of power failure, the turret may be trained by manual power. The training-gear A-end is connected through a clutch to two handcranks located on the shelf plate. By engaging this clutch the A-end may be driven by turning the cranks instead of by the motor. This form of operation is called *manual drive*. In manual drive, the training of the turret is controlled by the trainer's handwheels in the same manner as when power is used, but the training rate attainable is, as might be expected, much slower.

20F12. Operation of training equipment

Figure 20F7 is a functional diagram of the turret training system, showing the instruments described above. The path of quantities in the various methods of gun laying can be traced on this diagram.

20F13. Local gun laying

Local gun laying is used in local fire control. The target is located by means of the turret periscope, and the turret is trained until the target can be seen in the turret sights. Range, as measured by the local rangefinder, and turret train from the MTTI are set into the computer as hand inputs, and with these data, and the other hand inputs, a value of sight deflection is computed. This computed sight deflection is sent to the sight setter by phone, and he cranks the value into his sight setter's indicator, thus deflecting the pointer's and trainer's sights. The trainer operates his handwheels to keep his vertical crosslines on the target, and thus deflects the gun by the amount of the deflection angle turned into his sight. In local fire control no horizontal parallax correction to turret train is necessary.

In primary, secondary, and auxiliary fire control the turret may be trained in either indicator or automatic gun laying.

20F14. Indicator gun laying

In indicator gun laying, turret train response is corrected for parallax in the gun train indicator and compared with the gun train order on the dials of that instrument. Observing the dials, the trainer trains the turret in accordance with the orders received. Training of the turret is accomplished by means of

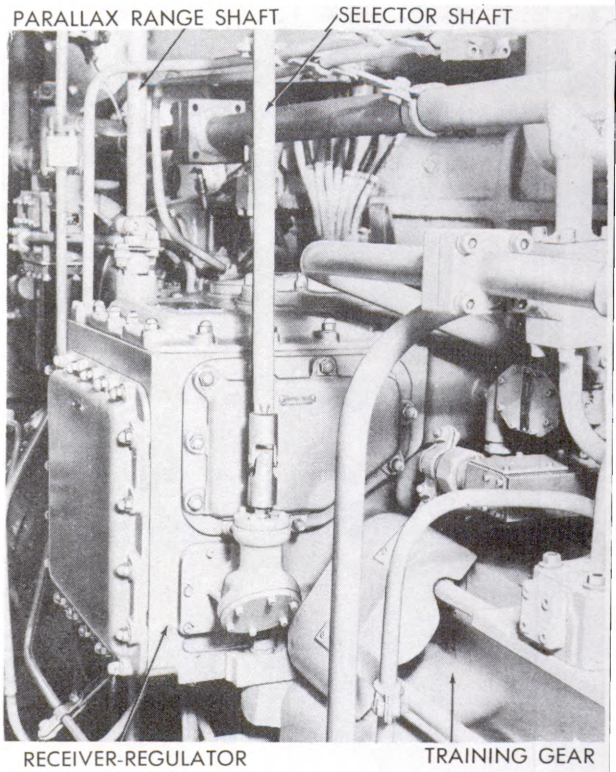


FIGURE 20F6.—The train receiver-regulator controls the turret training gear in automatic gun laying.

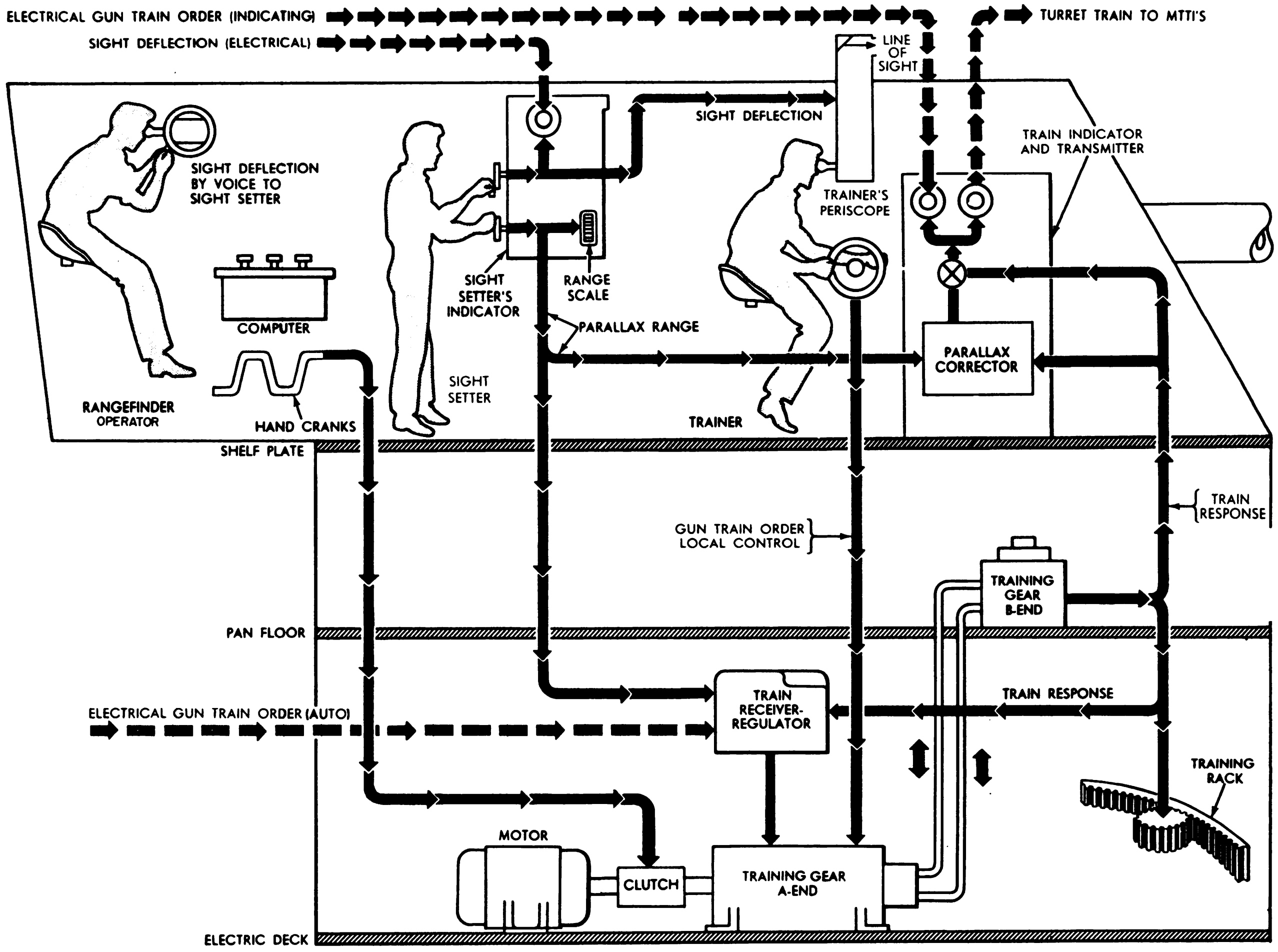


FIGURE 20F7.—Schematic diagram of the turret training system.

the trainer's handwheels, which control either the A-end of the training gear (hand drive) or the receiver-regulator (local power drive).

20F15. Automatic gun laying

In automatic gun laying, gun train order is received by the train receiver-regulator. This instrument also receives parallax range from the sight setter's indicator and turret train response from the B-end of the training gear. Combining these inputs, the receiver-regulator automatically controls the A-end of the training gear so as to bring the turret to the ordered position. In automatic gun laying the gun train indicator transmits corrected turret train to the multiple turret train indicators throughout the system.

20F16. Elevating equipment

The elevating equipment is similar in fundamental principles and operation to the training equipment. It consists of the pointers' handwheels, gun elevation indicators, elevation receiver-regulators, and the elevating speed-gear A-ends and B-ends. Each of the guns is elevated independently by its elevating gear, which is controlled either by the elevation receiver-regulator or by the pointers' handwheels, depending on the method of gun laying employed. The handwheels may be connected through a clutch to the tilting plate of the elevating gear A-end, or to the receiver-regulator. The pointer operates his handwheels either to bring the horizontal crossline of his telescope on the target, or to match dials on the gun elevation indicator. Figure 20F8 shows a view of the left pointer's station.

20F17. Gun elevation indicator

The gun elevation indicator functions in a manner similar to the gun train indicator. One of these is shown in figure 20F8 at the left pointer's station. In

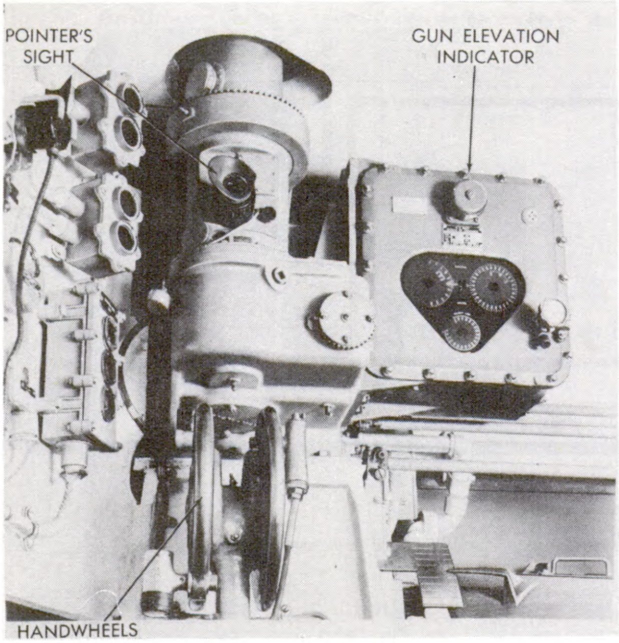


FIGURE 20F8.—Left gun pointer's station, showing the location of the gun elevation indicator.

indicator gun laying the gun elevation indicator receives gun elevation order electrically and gun elevation response mechanically. These values are indicated on the zero-reader and follow-the-pointer dials and are used by the pointer in elevating the gun in follow-the-pointer operation.

Before gun elevation response is compared with the order, two corrections are made within the indicator to the response signal. These are (1) roller-path tilt correction, and (2) erosion correction.

Roller-path tilt correction compensates for inclination of the turret's roller path plane with respect to the ship's reference plane for any angle of train of the turret. This correction varies with the position of the turret in train and with the inclination of the roller path. The inclination of the roller path is determined when the battery is aligned, and is set into the roller-path tilt mechanism by screw-driver adjustment. Train is received from the training gear. A computation based upon two inputs produces roller-path tilt correction for the particular train angle.

Erosion correction compensates for the reduced initial velocity of the projectile due to the erosion of the gun barrel as successive charges are fired. The effect of gun erosion on the trajectory varies with the range, which is a function of sight angle and the initial velocity of the projectile. The erosion corrector thus receives two inputs: sight angle, which provides the range function, and a hand input to account for the velocity loss. The usual practice is to put an initial velocity setting into the rangekeeper in Plot, or into the auxiliary computer in the fire control station, equal to that for the least eroded gun in the battery. A value of initial velocity loss, equivalent to the difference between the velocity set into the rangekeeper or computer, and the actual velocity obtained in the individual gun, is then set into each gun elevation indicator by means of the velocity-loss knob. A velocity-loss dial is provided to enable the operator to read the value of velocity loss introduced. Erosion correction and roller-path tilt correction are added (algebraically) to gun elevation response to produce modified gun elevation.

Summarizing, the inputs to the instrument are: Gun elevation orders, electrical; turret train, for the roller-path tilt correction; sight angle and velocity loss for the erosion corrections, and elevation response from the gun elevation attachment.

20F18. Elevation receiver-regulator

The elevation receiver-regulators control the elevating gears in accordance with gun elevation order. This order comes from the plotting-room switchboard or auxiliary switchboard, or from the pointer's handwheels. One of these instruments is shown in figure 20F9 located on the pan floor, beside the elevation A-end.

The elevation receiver-regulator, like the train receiver-regulator, is an electric-hydraulic follow-up

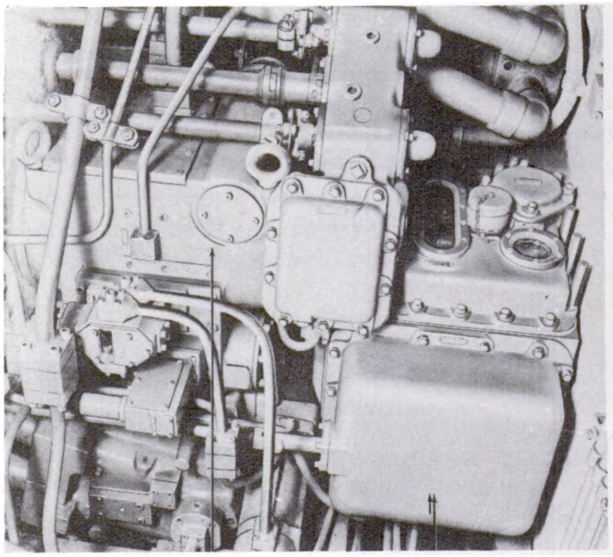


FIGURE 20F9.—The elevation receiver-regulator controls the elevating gear in automatic gun laying.

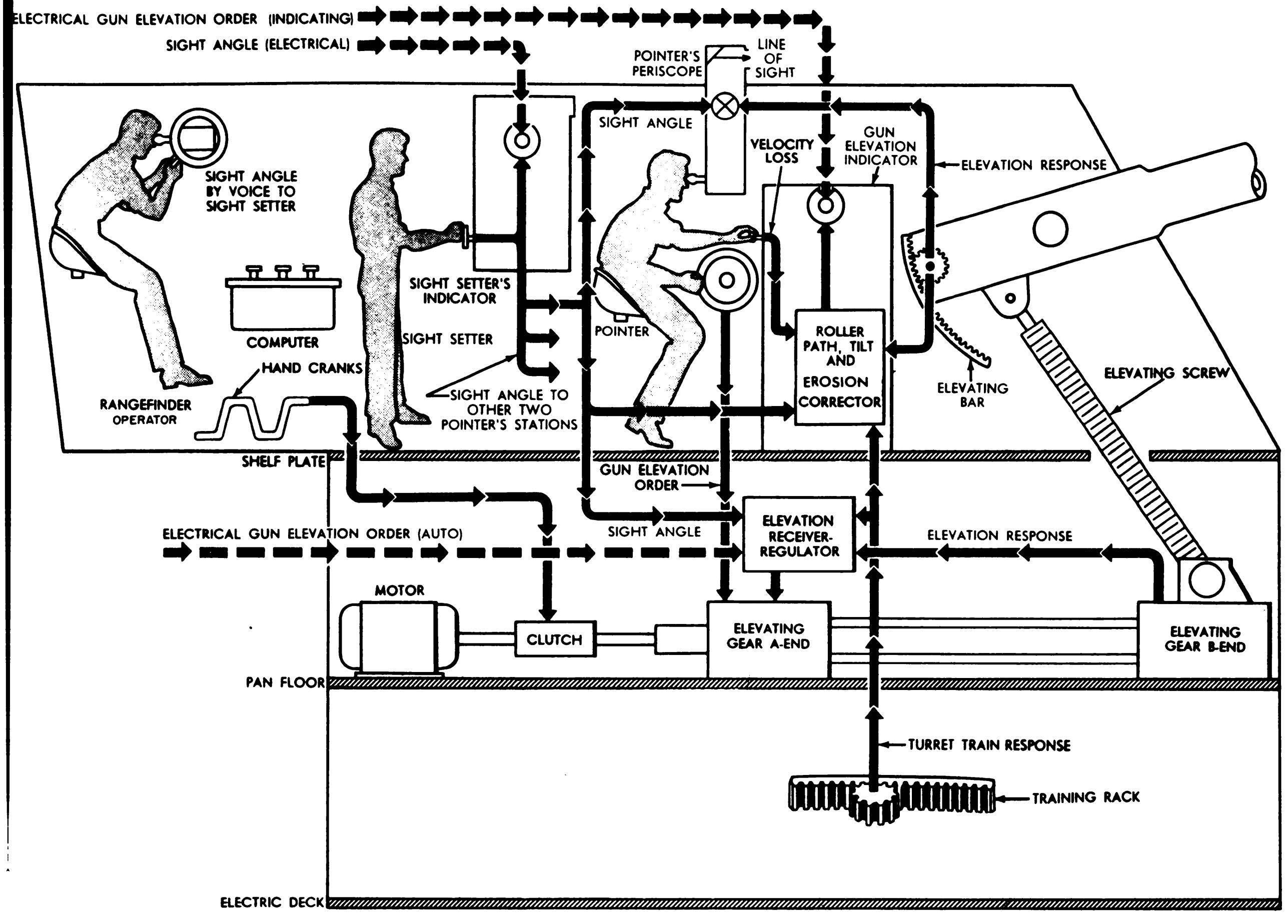


FIGURE 20F10.—Schematic diagram of the gun elevation system.

device. It controls the A-end of the elevating gear. The unit has correction mechanisms to correct gun elevation response for roller-path tilt and erosion, and to compensate for the non-linear relationship between elevating-screw rotation and gun elevation. The first two corrections are the same as those made in the gun elevation indicator. The receiver-regulator has a velocity-loss knob and dial, by means of which velocity loss may be set into it, in a manner similar to that for the elevation indicator. It also receives sight angle from the sight setter's indicator for computing erosion correction and turret train response from the training speed-gear B-end for computing roller-path tilt correction.

The elevating-screw correction compensates for the disproportionality between rotations of the elevating-screw nut and rotation of the gun about its trunnions. It should be noted that this correction is not necessary in the gun elevation indicator, because the elevation response input to this instrument is driven from a gear segment fastened to the gun, instead of from the elevating-screw drive; hence the proportionality of gun movement and response is constant for all gun elevations.

Gun elevation response, when corrected, is compared with gun elevation order, the difference between the two producing an error signal. This error signal controls the A-end of the elevating gear in such a way as to drive the gun to the ordered position.

A control selector at each pointer's station is connected to the receiver-regulator by shafting. When thrown to LOAD, the selector positions hydraulic valves so as to bring the gun rapidly to the loading position after it has been fired. An auxiliary selector at the pointer's station can be positioned to transfer loading control to the gun captain, which is the normal procedure. The gun captain may then exercise control by means of his ready switch. Return of the pointer's

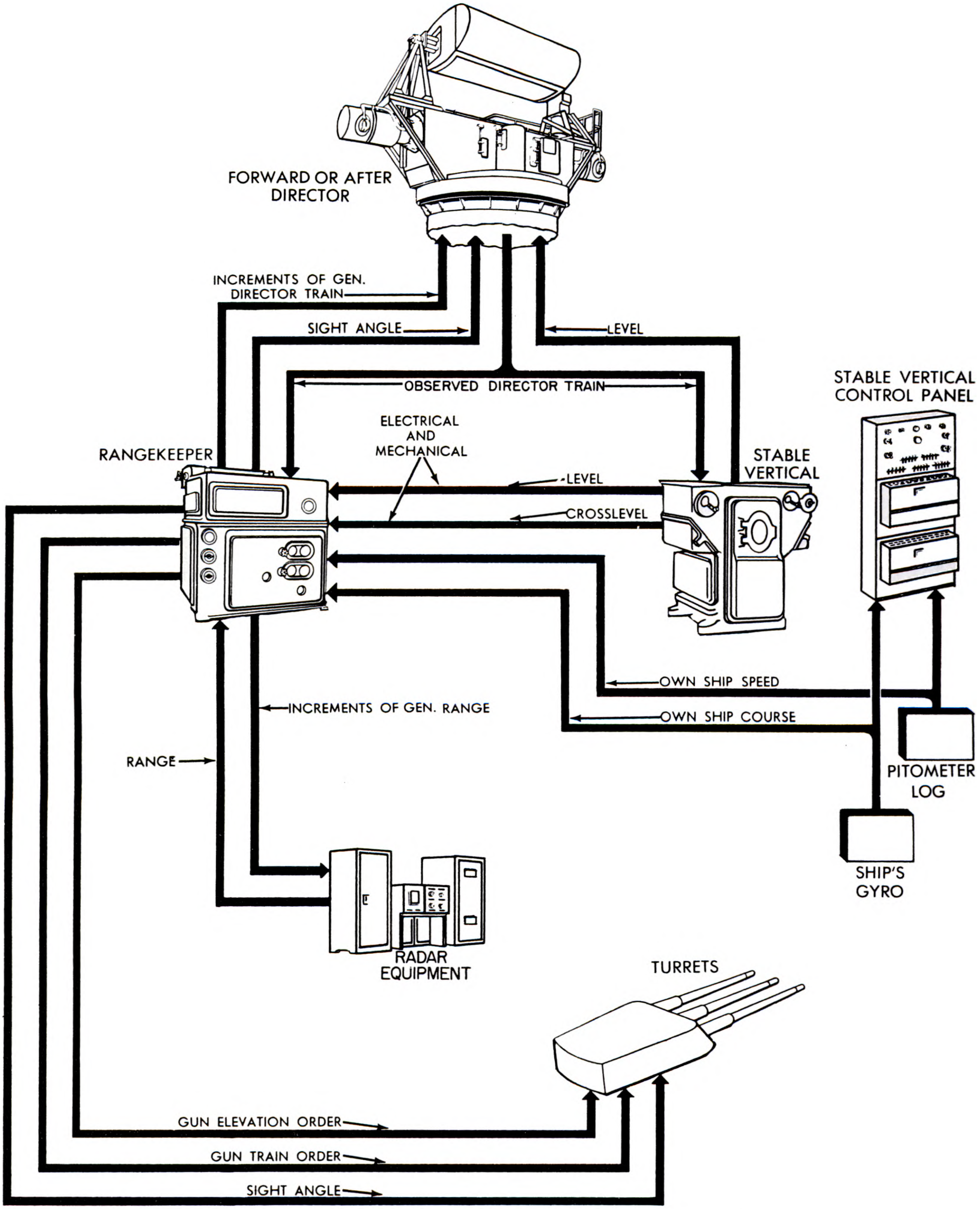


FIGURE 20F11.—The flow of quantities in primary fire control.

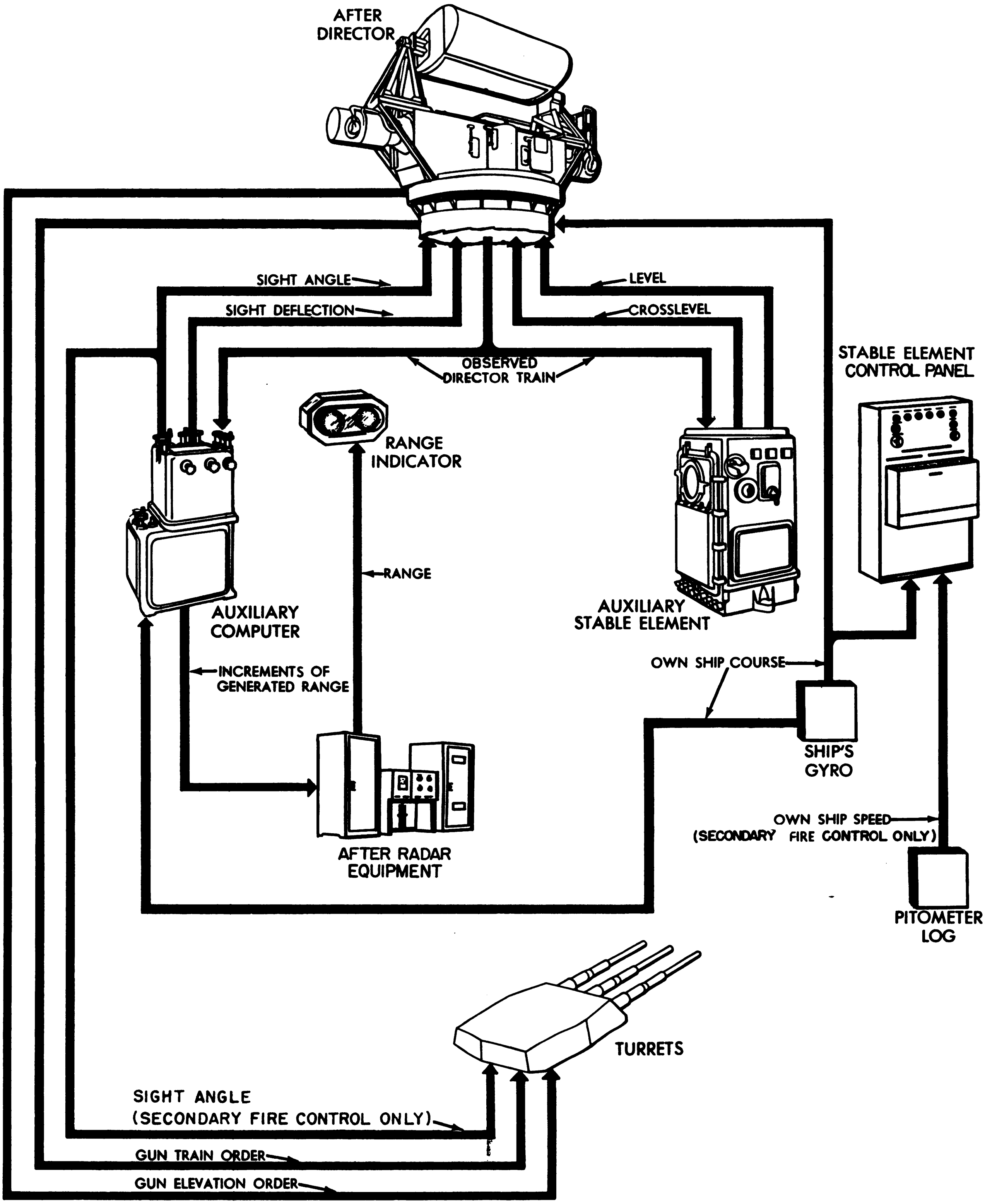


FIGURE 20F12.—The flow of quantities in secondary or auxiliary fire control (using the after director).

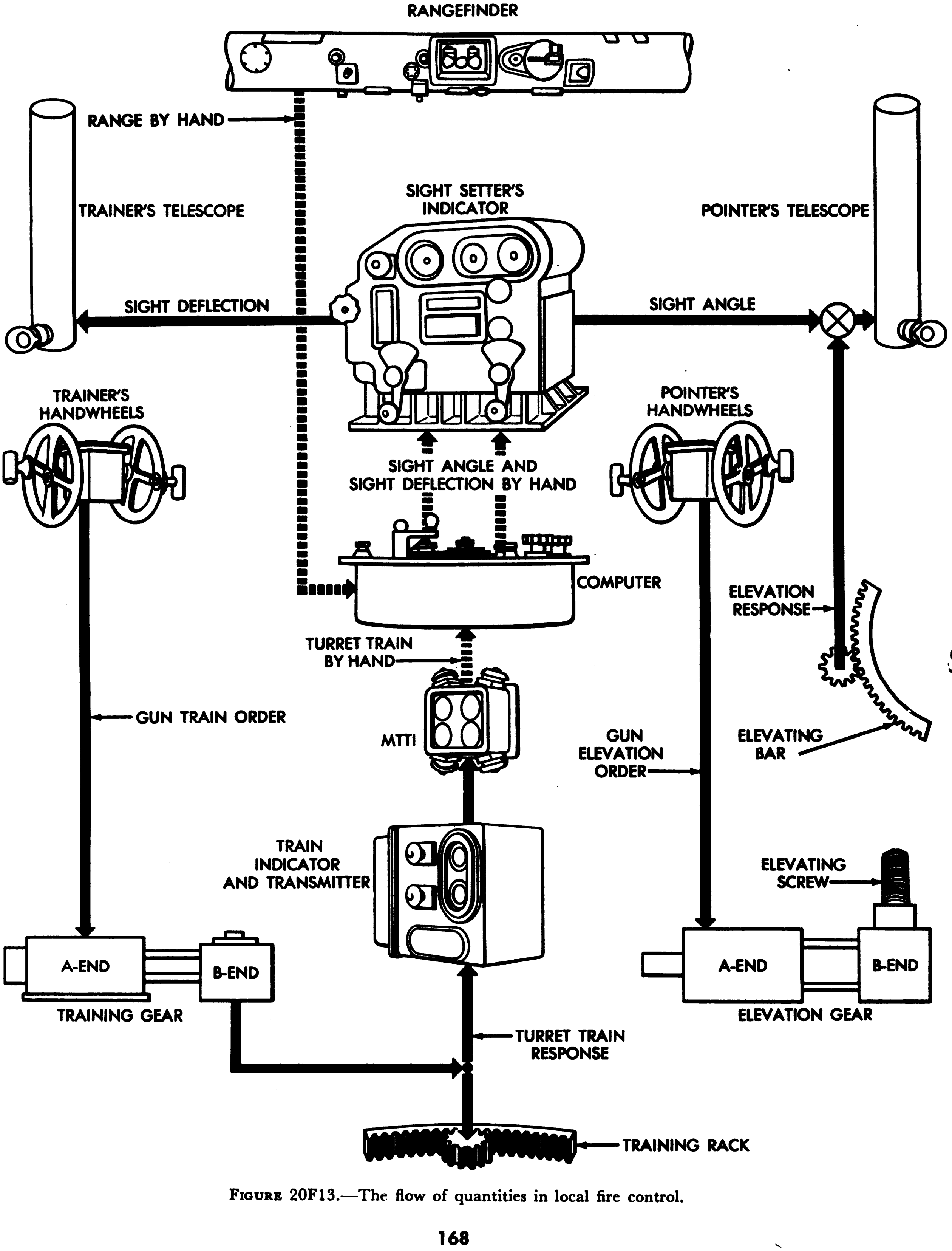


FIGURE 20F13.—The flow of quantities in local fire control.

elector to AUTO, or of the gun captain's switch to READY, causes the receiver-regulator to reposition the gun at the existing value of gun elevation order.

20F19. Elevating gear

Each gun is elevated by an elevating screw which travels through a nut rotated by the B-end of the elevating gear. Part of an A-end may be seen in figure 20F9. The gear consists of a hydraulic pump and motor similar to the training gear, and is controlled in the same way.

In manual drive, the A-end of the elevating gear may be connected, through a clutch, to the same hand cranks used for the training gear. The same clutch disconnects the electric motor. In manual drive, elevation is slower than in other methods.

20F20. Operation of elevation equipment

Figure 20F10 shows a functional schematic of the operation of the elevation system. There are three duplicate sets of elevation equipment—one for each gun—only one of which is shown. The equipment is located on the shelf plate, at the pointers' stations, and on the pan floor.

20F21. Local gun laying

In local gun laying, as explained in article 20F13, the computer furnishes the values of sight angle and sight deflection. Sight angle is received by phone from the computer operator and set into the sight setter's indicator by the sight setter. Motion of the hand crank depresses the line of sight in relation to the gun bore. Sighting through the depressed telescopes, the pointers operate their handwheels to elevate the guns until the horizontal crosslines are on the target. The handwheels control either the A-ends of the elevating gears (hand drive), or the receiver-regulators (local power drive).

If manual drive is used, the operation is the same, except that manpower is supplied to the A-end from the hand cranks instead of electric power from the motor.

In primary, secondary, and auxiliary fire control, the guns are elevated in accordance with an electrical gun elevation order. In each case, the guns may be elevated in either indicator or automatic gun laying.

20F22. Indicator gun laying

In indicator gun laying the gun elevation order positions the follow-the-pointer inner dials of the gun elevation indicators. The pointers operate their handwheels to match the dials. By so doing they control the A-ends of the elevating gears, which control the elevation of the guns. The elevation of each gun is transmitted mechanically from the elevating arc as elevation response back to the gun elevation indicator. Here the elevation corrections are added to gun elevation response to produce modified gun elevation, which restores the zero-reader dial and positions the follow-the-pointer ring dial.

In auxiliary fire control, sight angle is not available on the dial of the sight setter's indicator, but must be supplied by the local computer or from some other source by telephone.

20F23. Automatic gun laying

In automatic gun laying the gun elevation order is received by the elevation receiver-regulators, which automatically control the A-ends of the elevating gears, and thus the elevation of the guns.

The receiver-regulators also receive sight angle and velocity loss for computing the erosion correction, and turret train response for computing the roller-path tilt correction, as do the elevation indicators.

20F24. Turret inputs and outputs

The quantities received by the turrets are:

1. Gun train order (automatic, indicating, and information).
2. Gun elevation order (automatic and indicating).
3. Sight angle.
4. Sight deflection.
5. Adjacent turret train (in turrets **1** and **2**).

The outputs are:

1. Turret train (information).
2. Optical range.

Some of the types of fire control which may be used were briefly discussed in article 20B4. Figures 20F11, 20F12, and 20F13, which are flow diagrams for primary, secondary, and local fire control respectively, should assist in an understanding of what takes place in these types of control.

G. Main-Battery Radar

20G1. General

Two radars are used with present-day main-battery fire control installations. These are Radar Equipment Mark 13 Mod 0 and Radar Equipment Mark 8 Mod 3. Although the Mark 13 has almost completely replaced the Mark 8 Mod 3 in the Fleet, the Mark 8 Mod 3 may still be found on some ships. Therefore a short description of this radar is given later (p. 182).

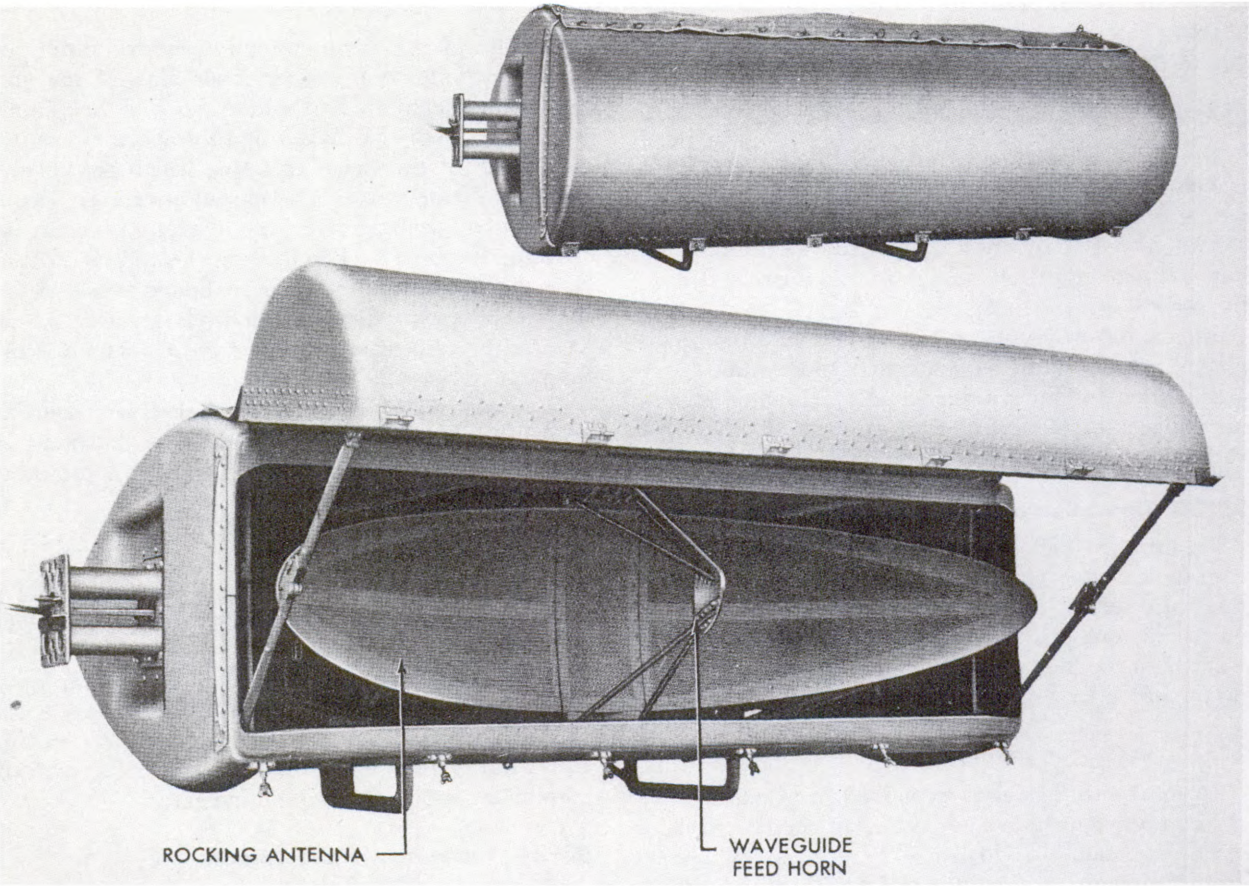


FIGURE 20G1.—Antenna assembly, front open and closed.

In studying this section the student may find reference to chapter 16 helpful.

20G2. Cruiser radar installation

The modern cruiser has two Mark 13 radars installed, one for use with each of the two Mark 34 directors. The antenna, which scans by rocking back and forth horizontally, is mounted on top of the director (fig. 20G1), and the radar transmitter-receiver is located inside the director.

The main radar control unit for the forward Mark 13 radar is located in the main-battery plotting room near the Mark 8 rangekeeper. This unit, known as the control console (fig. 20G2), is controlled by the radar operator.

The control console for the after radar is located in the after main-battery control station topside, adjacent to the Mark 3 auxiliary computer. The radars are normally operated from the control consoles. However, provision is made for shifting control of either radar from the console to a remote-control unit (fig. 20G3) at the control officer's station in the associated director.

Two remote range and train indicators (fig. 20G4) are located in each director, one to aid the trainer in getting on target by radar, and one to provide the control officer with continuous target data and to enable him to spot fall of shot.

In addition, two remote range and train indicators, one for each radar, are installed adjacent to each main-battery rangekeeping instrument—the Mark 8 rangekeeper in the plotting room, the Mark 3 computer in the forward topside control station, and the Mark 3 computer in the after topside control station. These remote indicators give the same B-scope presentations seen on the control consoles, and associated range counters give direct range readings for use of the rangekeeper or computer operator. Fall of shot may also be spotted from remote indicators.

Other components of the radars are below decks.

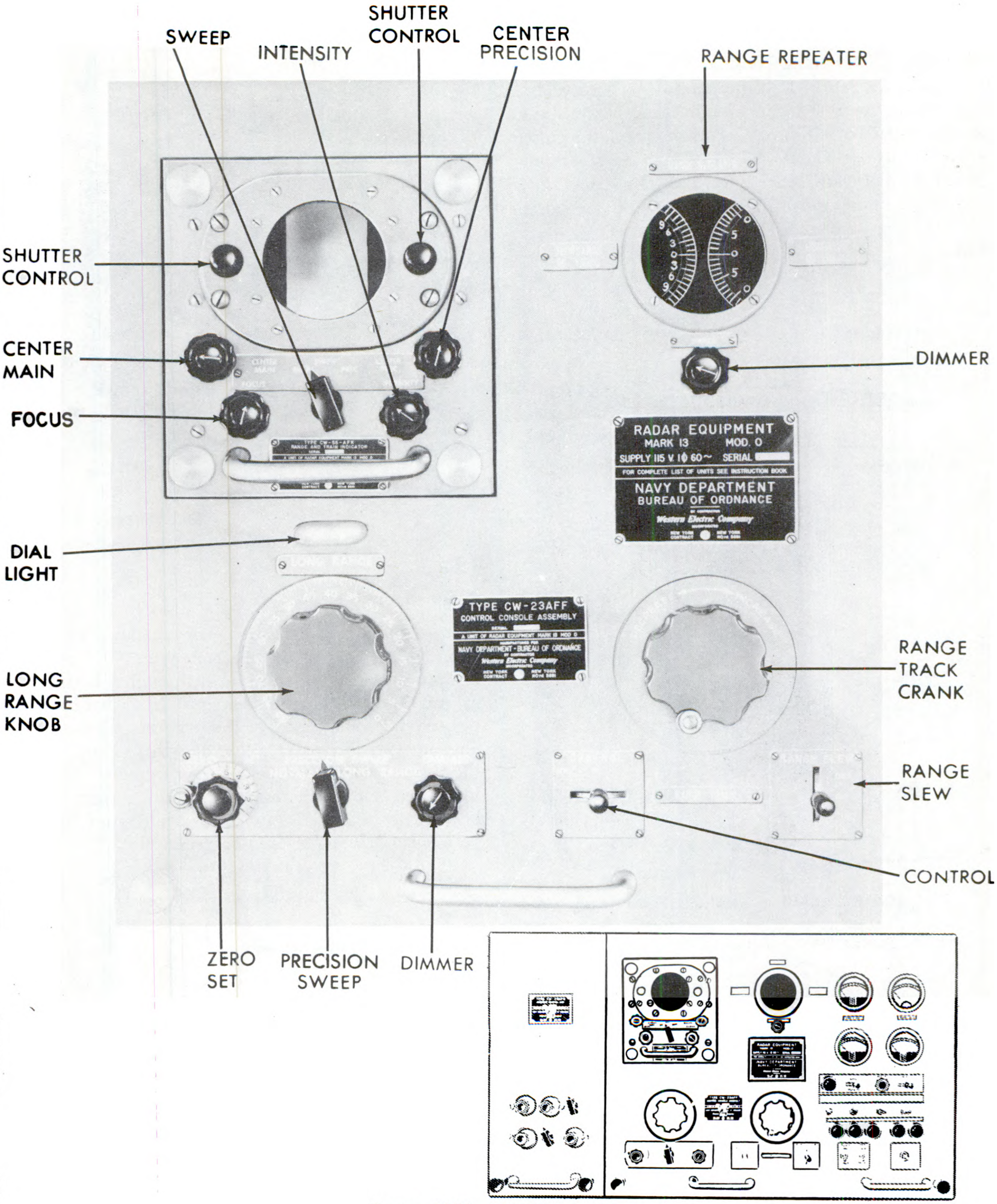


FIGURE 20G2.—Control console.

20G3. Beam characteristics

Figure 20G5 illustrates the radar beam of the Mark 13 radar. This beam consists of a series of pulses emitted at the rate of 1,800 per second, each pulse lasting 0.3 microsecond. Since radio energy travels at a constant speed of 328 yards per microsecond, the pulses theoretically are about 100 yards long or are represented by a 50-yard range interval on the scope, since scope presentations are for round trips of the pulses. The time interval between emission of pulses is 555 microseconds. Since the time required for a pulse to travel out 80,000 yards and return is 488 microseconds, there is ample time for each pulse to travel the maximum range and return before the next pulse starts.

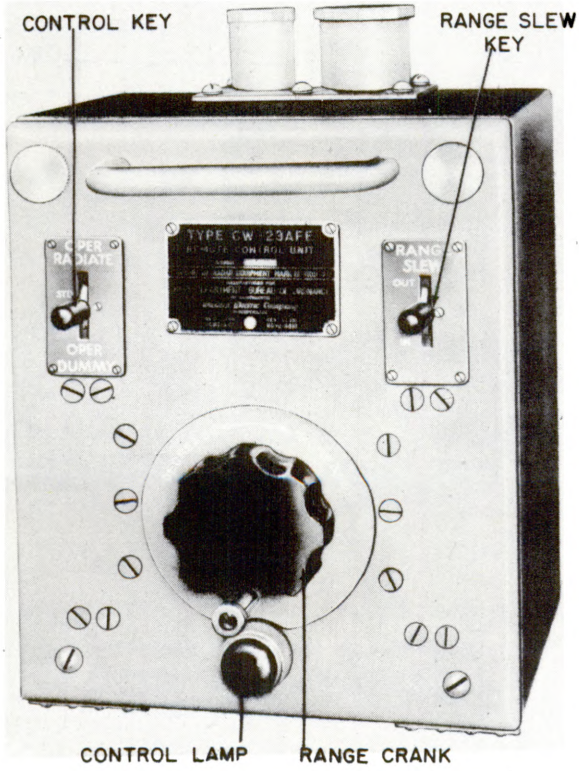


FIGURE 20G3.—Remote-control unit.

In Radar Equipment Mark 13 Mod 0 the beam is 0.9° wide and 3.6° high. Actually, the radar beam is not as sharply defined as appears in figure 20G5. It is strongest at points along its axis, becoming weaker as the angular distance from the axis increases.

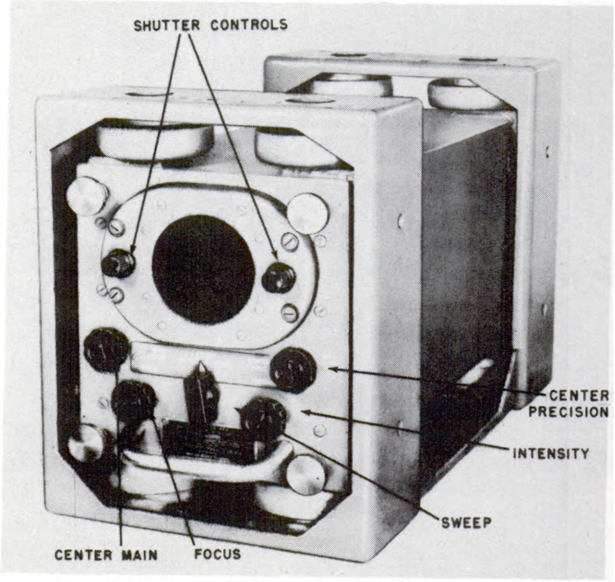


FIGURE 20G4.—Remote range and train indicator.

20G4. Scanning

In scanning (fig. 20G6), the rocking antenna mounted on top of the director causes the narrow beam to progress back and forth through a horizontal arc of 11.5° (200 mils) five times in each direction per second. The center of the scanning arc is rigidly aligned with the director line of sight, so that when the director is trained on a target, accurate bearing indication is given by the radar. With respect to the bearing of the director, the radar beam scans an area between +5.75 and −5.75 degrees.

NOTE. Positive (+) signifies increasing bearing, and negative (−) signifies decreasing bearing.

20G5. Scope presentation

The scope presentations seen on the control console and on the remote range and train indicators are identical, and are B-type presentations. In this type of presentation, own ship is at the bottom of the scope, and the picture seen is that of a narrow, wedge-shaped segment of the earth. Figures 20G7 and 20G8 show the appearance of the scopes, both on the control console and on the range and train indicators, when set to MAIN SWEEP and when set to PRECISION SWEEP—NORMAL. Whenever the radar equipment *views* a target, a bright spot (the echo from the target) appears on the scope. The centerline or zero bearing line is aligned with the line of sight of the director. The

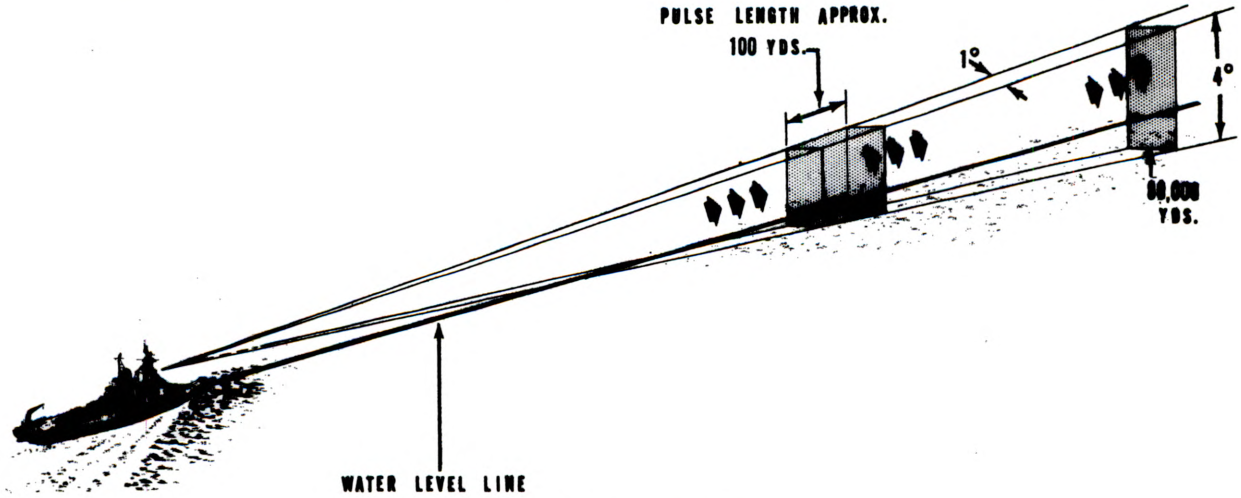


Figure 20G5.—Radar beam.

distance between vertical lines represents intervals of approximately 50 mils in bearing. When the field of view starts at zero yards, the wide horizontal line at the bottom of the scope marks the outgoing pulse. All ranges are measured upward from this horizontal line. The narrow dotted and solid horizontal lines are called the normal-range line and the long-range line respectively. They are independent of each other; their operation is described in the following paragraphs.

20G6. Types of sweep

There are available in the Mark 13 radar three types of sweep: main sweep, precision sweep—normal, and precision sweep—long-range.

Main sweep. On main sweep the operator can view out to 80,000 yards. The total range appearing on the scope at any time (fig. 20G9) may be varied from 40,000 yards to the entire 80,000 yards. It is recommended that the field of view be set to 50,000 yards (fig. 20G10). The operator can then view any 50,000-yard section of this 80,000 yards by adjusting the *center main* control (see fig. 20G2) on the console, which moves the field across the scope in the same manner that a window shade may be moved behind an opening (fig. 20G9).

There are three solid bearing lines, the outer lines each 50 mils out from the center bearing line. The total width of the scope is approximately 200 mils, 100 mils either side of the center bearing line.

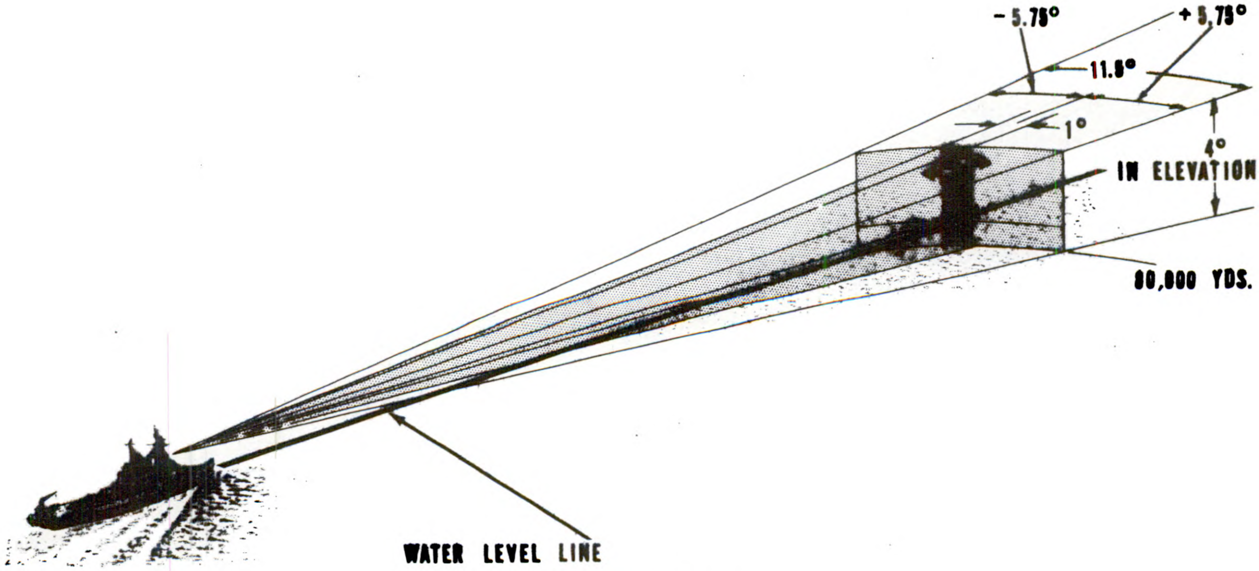


Figure 20G6.—Scanning.

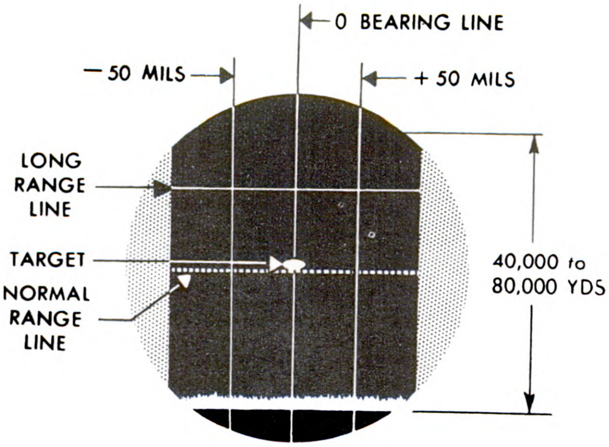


FIGURE 20G7.—Main sweep.

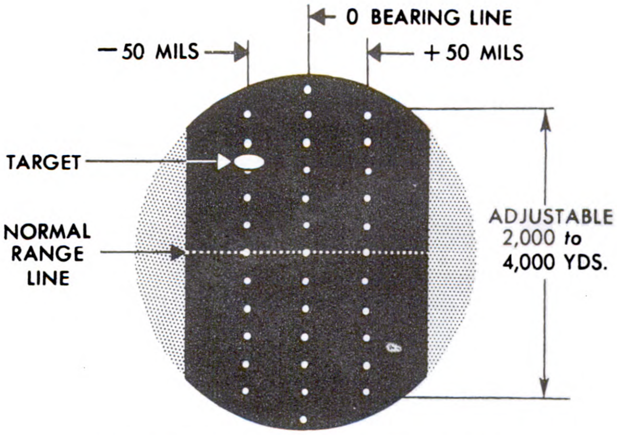


FIGURE 20G8.—Precision sweep—normal.

Two range lines are visible on main sweep. The long-range line, which is solid, is controlled by the *long-range* knob, and moves over the face of the scope to the maximum of 80,000 yards. The normal-range line, which is dotted, is controlled by the *range-track* crank and moves over the face of the scope only to 50,000 yards. The operator shifts the range line until it touches the bottom of the echo. The range to the target can then be read from the long-range dial or the *range repeater.*

Precision sweep—normal. On precision sweep the operator can view to a maximum of 50,000 yards, but only 2,000 to 4,000 yards of this at a time. The desired visible field on precision sweep, which may be any value between 2,000 and 4,000 yards, is set by an internal adjustment and usually is not changed by the operator. In this discussion it is assumed that the selected field visible on the scope is 2,000 yards (fig. 20G11). The operator can select any 2,000- to 4,000-yard section out of the normal 50,000 yards available. This is done by operating the *range-track* crank, which moves the visible field in the scope in the manner of a roller shade. The range line is dotted and fixed in the center of the scope. Note that on precision sweep the *field,* and not the range line, moves during ranging. When the echo rests upon the range line, range to the target can be read from the *range repeaters.* Bearing lines are made up of dots indicating spaces 200 yards apart.

Precision sweep—long-range. The long-range unit can be used with precision sweep out to 80,000 yards, but range must be read from the *long-range* dial with its coarse graduations, and will not be as accurate as with the normal-range unit, the range reading dials of which have graduations as small as 10 yards. Precision sweep—long-range is used for observation only;

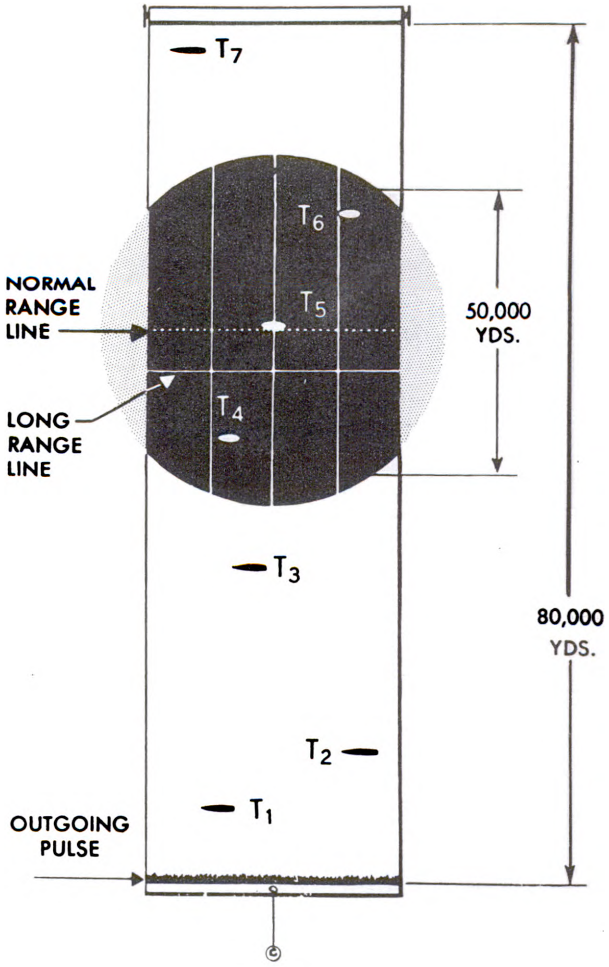


FIGURE 20G9.—Main sweep, changing visible section.

SWEEP CHARACTERISTICS, RADAR MARK 13

Range (Yards)	*Visible Range Adjustable (Yards)*	*Bearing Lines*	*Normal-Range Line*	*Long-Range Line*
Main Sweep—0 to 80,000...	40, 000 to 80,000..	Solid.....	Dotted to 50,000 yards only.	Solid to 80,000 yards.
	NOTE: Range lines move when ranging.			
Precision Sweep—Normal—0 to 50,000.	2,000 to 4,000.....	Dotted...	Dotted Centered in scope.	(None).
	NOTE: Visible field moves when ranging.			
Precision Sweep—Long-Range—0 to 80,000.	2,000 to 4,000.....	Dotted...	(None)............	Solid Centered in scope.
	NOTE: Visible field moves when ranging.			

range is not transmitted to the rangekeeper. In this case the solid long-range line is also fixed in the center of the scope.

A recapitulation of sweep characteristics of Radar Equipment Mark 13 Mod 0 is given in the table above.

20G7. Range measurement

The lapse of time required for a pulse to travel from antenna to target and return is measured by the radar equipment, and range is visually represented on the scope by the distance from the transmitted pulse to an echo.

With the main sweep, to track the target in range, the operator brings either range line to the lower edge of the echo. With the precision sweep, the operator moves the echo until it lies on the range line. Figure 20G13 shows the correct setting of an echo.

20G8. Tracking in bearing

To track the target in bearing, the director trainer (viewing his remote range and train indicator) trains the director until the zero (center) bearing line on the scope bisects the echo. It is highly important that both the trainer and the radar-range operator keep the target echo properly located with respect to the bearing and range lines as long as they are tracking. Unless they do, the plotting room will receive incorrect information.

As mentioned earlier, the radar operator has a switch on his console (fig. 20G2), by means of which he can transfer ranging control from the console (switch on LOCAL) to the director officer's remote-control unit (switch on REMOTE).

Another switch on the control console allows the radar operator to quickly align the target echo and the range line when first picking up the target. This is known as the *range slew switch.*

20G9. Accuracy and resolution

The specified range accuracy for the normal range unit is ± [15 yards + 0.1 percent of the measured range], and for the long-range unit is ± 1.0 percent of the measured range. Therefore, with the units ranging on target at 3,000 yards the normal-range unit will be accurate to within ± 18 yards, the long-range unit to within ± 30 yards; and on a target at 30,000 yards, the normal-range unit will be accurate to within ± 45 yards, the long-range unit to within ± 300 yards. Advantage can be taken of the higher range accuracy of the normal-range unit out to a maximum of 50,000 yards.

Target bearing accuracy is ± 0.1 degrees (2 mils), or better. If exact alignment were possible, an accuracy of ± 1 mil might be attained.

Resolution—that is, the minimum separation between two targets in order that accurate range and bearing of either target may be obtained—depends upon beam width and pulse length. The narrow beam (1 degree) and short pulse (0.3 microseconds) of the Radar Equipment Mark 13 Mod 0 give excellent resolution in both bearing and range, particularly on precision sweep.

The length in range of the target echo gives an indication of the minimum separation between two targets on the same bearing which will permit complete resolution of those targets in range.

This echo length on Radar Equipment Mark 13 Mod 0 is about 100 yards for a target of negligible range depth.

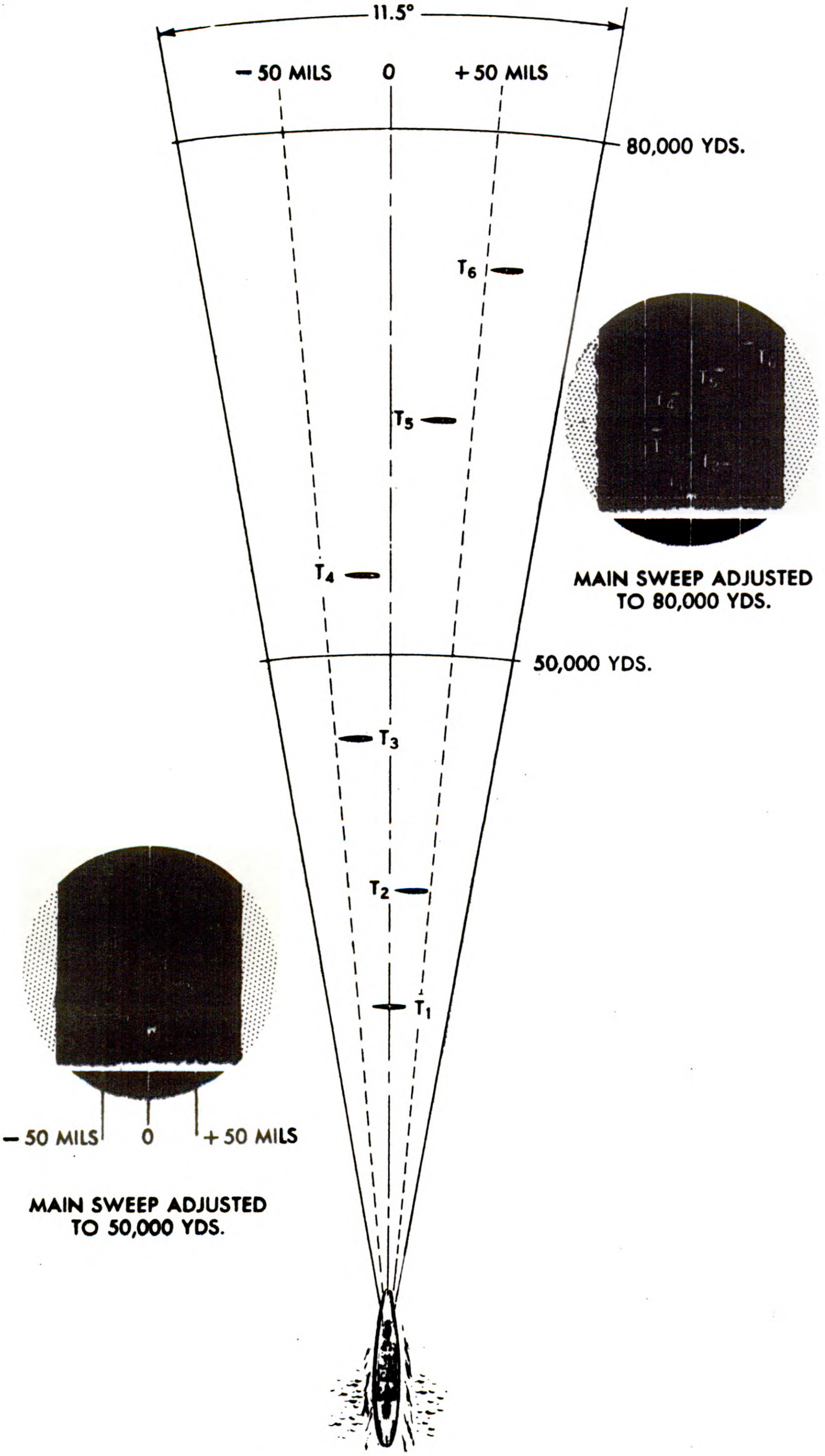


Figure 20G10.—Main sweep coverage.

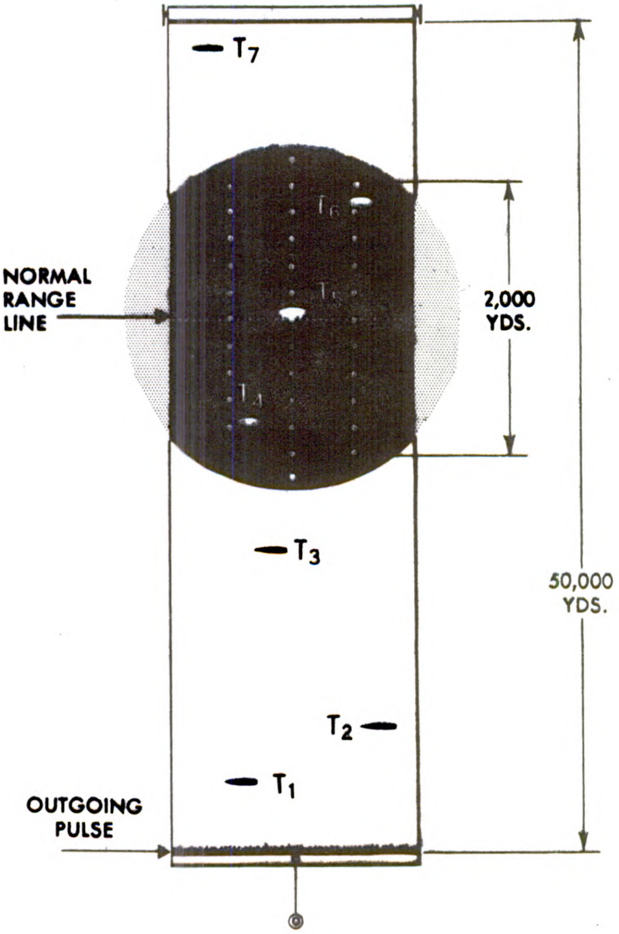


FIGURE 20G11.—Precision sweep—normal, changing visible section.

If two targets are separated in range by slightly more than 100 yards, energy reflected from the second target will reach the position of the first target on its way back to the antenna just after the last reflected energy has left the first target, and a separate echo will appear for each target. But if the two targets are separated in range by less than 100 yards, the first reflected energy from the second target will reach the position of the first target while energy is still being reflected from it, and a single large echo will appear.

Resolution of two targets at the same range but different bearings depends upon the beam width. The beam width is approximately 1 degree. Therefore, if two targets are separated by more than 1°, the beam leaves the first target before it strikes the second, and two echoes will appear upon the scope. If the separation of two targets is less than the beam width of 1°, a single wide echo (generally asymmetrical) will appear. Referring to figure 20G14, targets 1 and 2 as seen from position B and targets 3 and 4 as seen from position A are sufficiently separated to give good bearing resolution, whereas targets 3 and 4 as seen from position B and targets 1 and 2 as seen from position A are too close together in bearing.

It should be apparent to the student that the separation in yards necessary for bearing resolution between two targets varies with range; thus, as the targets become closer to own ship, one merged target pip

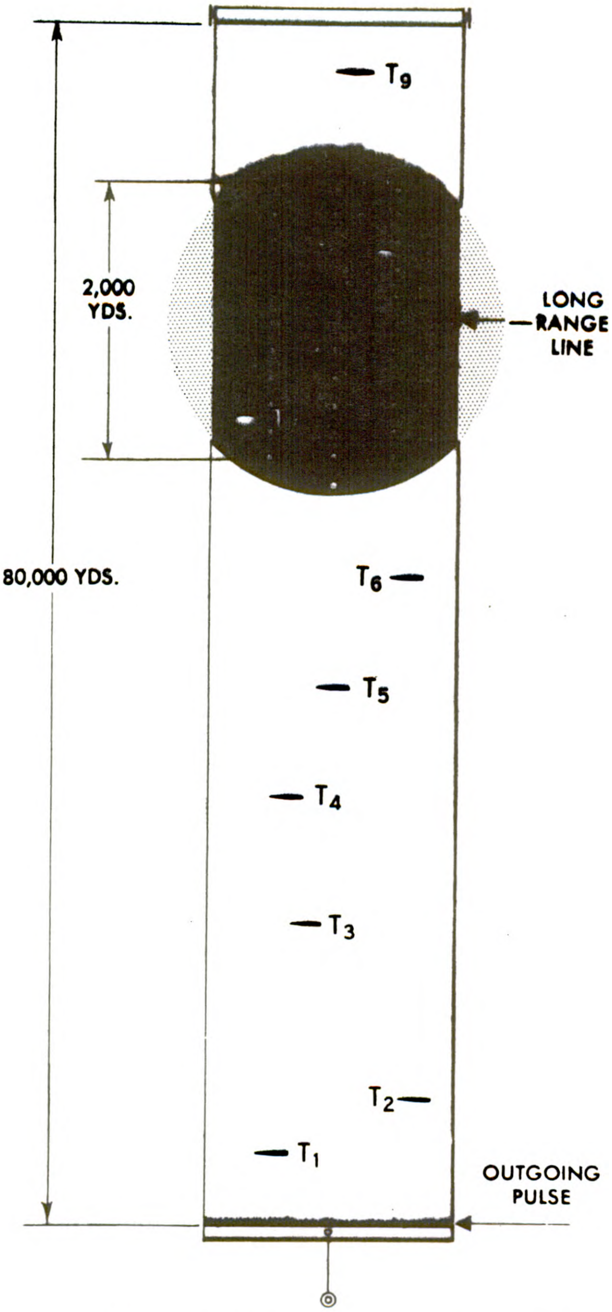


FIGURE 20G12.—Precision sweep—long-range, changing visible section.

may separate into two single pips. Also, an experienced operator can often improve the bearing resolution by judicious use of the RECEIVER GAIN control. By reducing the gain, two signals which merge may be wholly or partially separated.

20G10. Distortion

Since a B-scope does not show the true plan-view relationship of targets but shows a pie-shaped segment of the earth's surface as a rectangle, the result is a picture somewhat distorted in range and bearing. As will be explained, distortion in bearing is not the same as distortion in range. In order to interpret B-scope presentations properly, the operator must be familiar with the effects of distortion; at the same time, however, it is important to remember that neither kind of distortion in any way affects the accuracy of range and bearing to a target whose echo is properly set on the range lines and bisected by the zero bearing line.

Range distortion. Range distortion is present in Radar Equipment Mark 13 Mod 0, since arcs of circles drawn from own ship as center appear on the scope as straight lines. However, because of the small angle (11.5°) through which the beam scans, range distortion is insignificant except at long ranges, and may be ignored.

Bearing distortion. The distortion in bearing is of much greater magnitude and therefore of greater importance to the radar operator concerned with the method of presenting the scanned surface area on the B-scope. Bearing distortion should be understood by all officers and operators, because all targets in the scanned sector within the range of the equipment will appear on the scope in a distorted plan view. The relationship of one target to another on the scope will depend upon the range of the targets. Where it is possible to see both the B-scope and a PPI at the same station (as in the fire control tower of large ships) the two indications will not necessarily be similar. The distortion is most apparent when shore lines, islands, or large groups of ships are involved. In shore bombardment problems this distortion will be of greatest importance. When B-scope charts of a target are drawn in advance from navigation charts, the effect of the distortion at the expected range must be included. The nature of this distortion will be clear when the factors discussed in succeeding paragraphs are understood.

An explanation of bearing distortion when operating on main sweep follows. Figure 20G15 shows the yardage visible on the screen at various settings of the main sweep. The yardage represented by the width of the screen at the top is proportional to the maximum range to which the main sweep is set. For example, when the main sweep is set to show a maximum range of 40,000, 60,000, or 80,000 yards, the total yardage visible in bearing at the top of the screen is 8,000, 12,000, or 16,000 yards, respectively. As you progress down, the bearing yardage decreases. Assume that the main sweep is set at 50,000 yards and that three target ships, each 2,000 yards apart, approach the radar ship on straight, parallel courses (fig. 20G15). As they advance, the echoes of the two outside ships will diverge until they leave the screen at approximately 20,000 yards, while the center echo will continue along the center bearing line. The intervals in bearing between targets in a group will therefore appear to vary with the range, as indicated in figure 20G15. The picture of groups of targets on the B-scope is distorted so that wrong conclusions might easily be drawn from optical viewing only. The picture on the B-scope gives somewhat the appearance of perspective in bearing, but there is no foreshortening in range. It is seen from this illustration that the reason for the bearing distortion is that radial bearing lines in the scanned sector are represented by vertical parallel lines on the B-scope. A wedge-shaped sector of the earth's surface is displayed on the scope as a rectangular area.

It should be particularly useful at this time to study in detail how varying linear values appear on the pre-

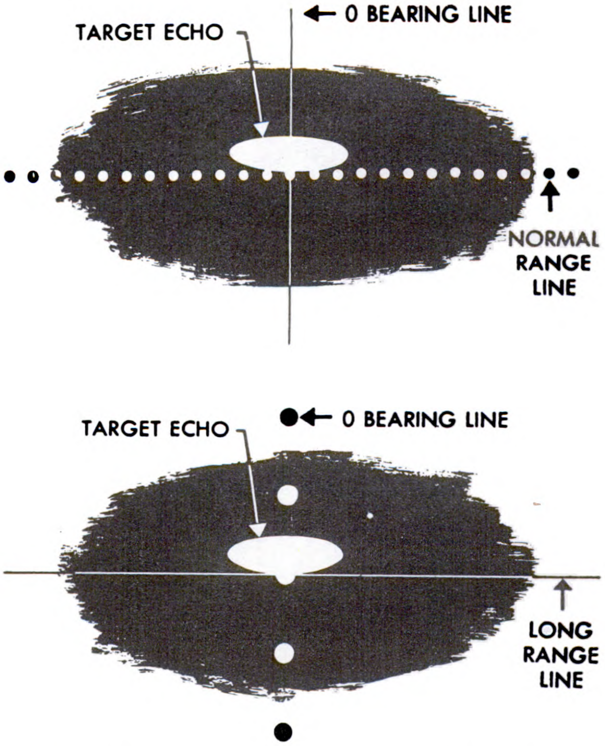


FIGURE 20G13.—Correct setting of echoes for ranging.

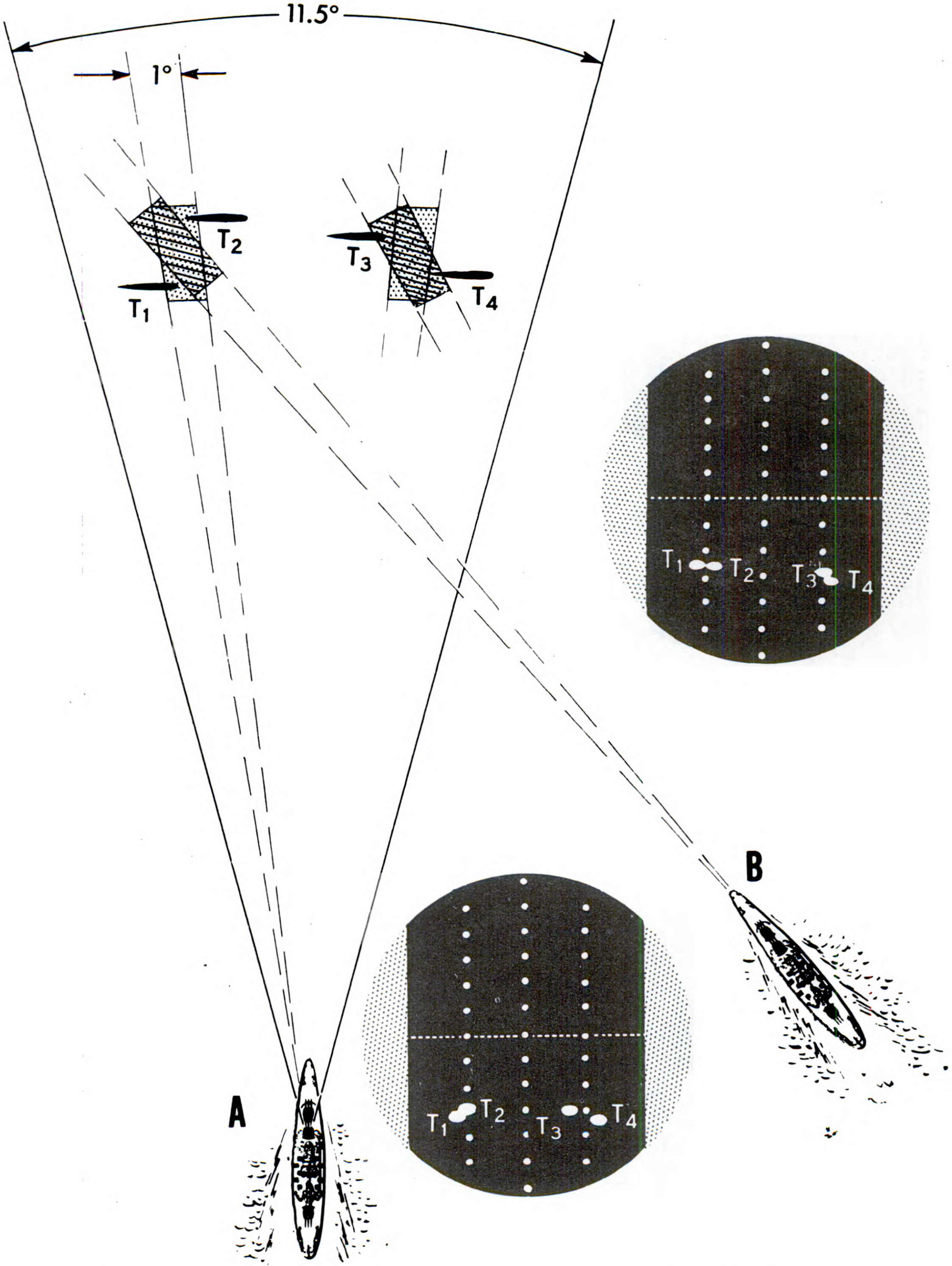


FIGURE 20G14.—Effect on target resolution produced by change in point of observation.

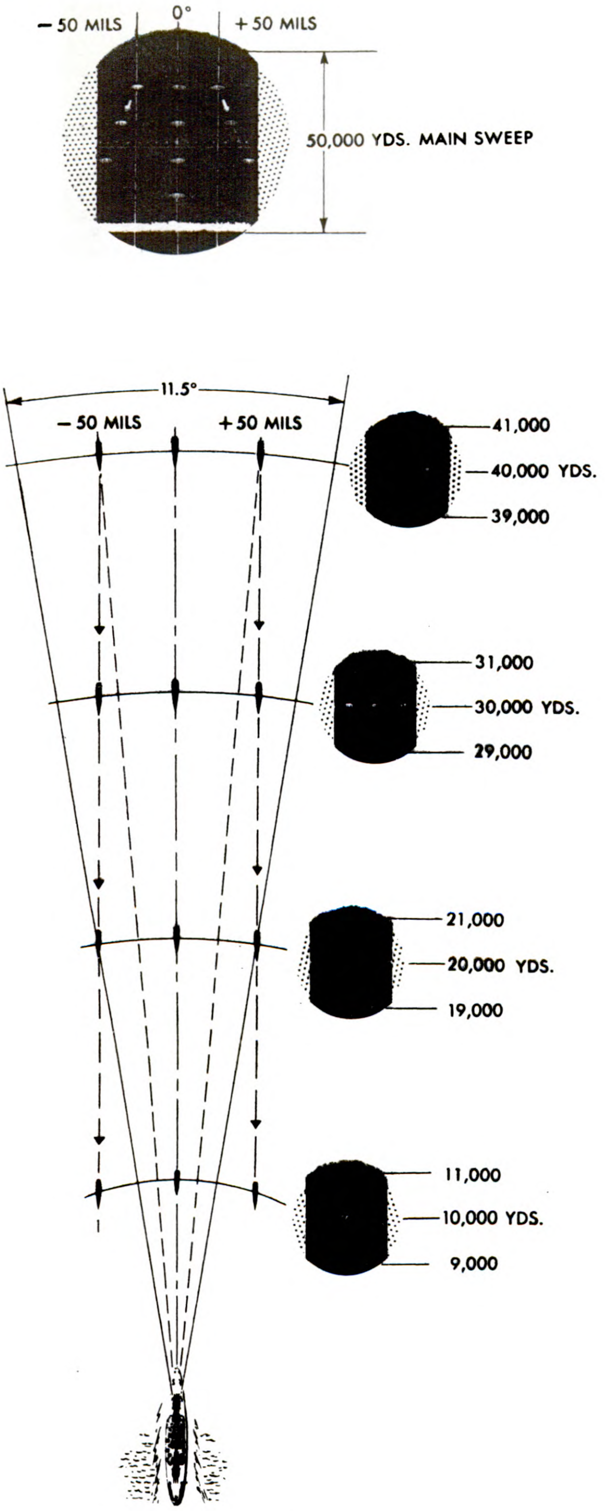


FIGURE 20G15. —Distortion in bearing.

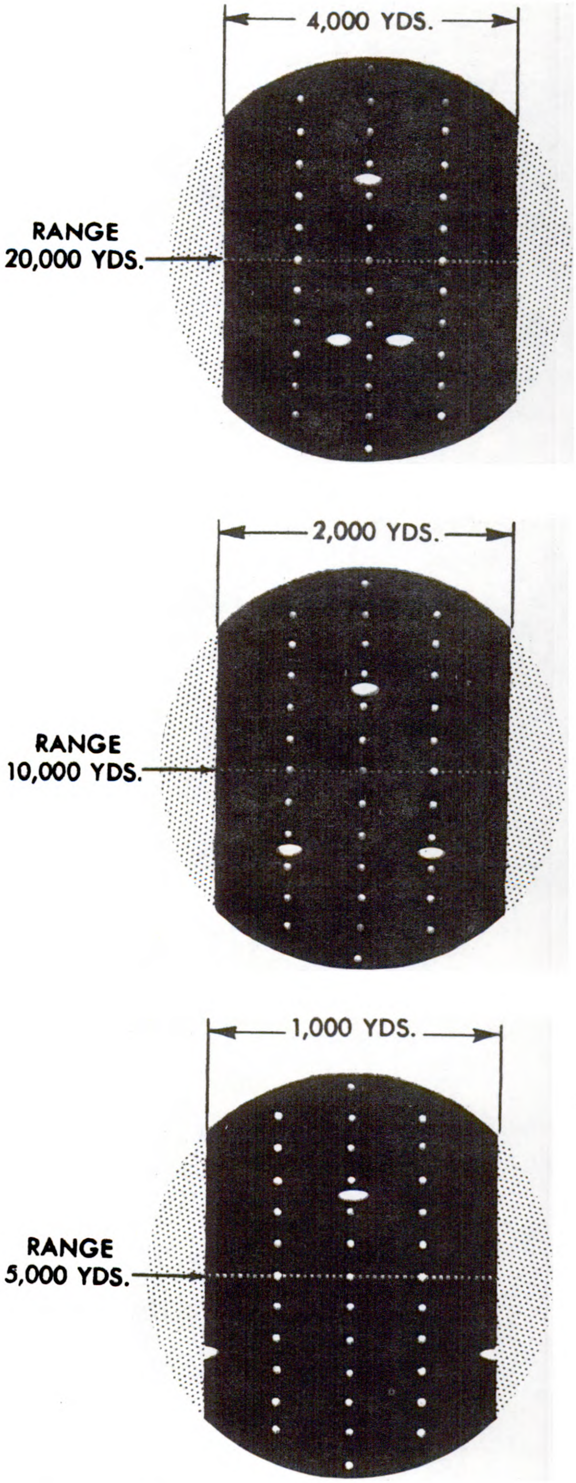


FIGURE 20G16.—Linear distortion in bearing.

cision sweep for the same angle at different ranges. Precision sweep shows not the total range from the radar ship to the extreme of the sweep, but only the selected 2,000- to 4,000-yard range portion. The following discussion assumes the sector to be 2,000 yards. Figure 20G16 shows groups of targets at 20,000-, 10,000-, and 5,000-yard range and precision sweep's appearance when viewing each group of targets. The two targets at the same range are separated 1,000 yards in bearing. The target on the center bearing line is at 1,000 yards greater range than each of the two outer targets. At 20,000 yards the width of the scope in bearing represents 4,000 yards, the interval in range 2,000 yards. A range interval of 1,000 yards covers the same distance on the scope as a bearing distance of 2,000 yards.

At a range of 10,000 yards the B-scope will show almost the true relative positions of the targets, because the 11.5° sector will be 2,000 yards wide, which is the same as the 2,000-yard range interval of precision sweep. Both the height and the width of the scope will represent 2,000 yards. Therefore, it is only at a range of 10,000 yards that the targets will appear substantially without distortion.

At a range of 5,000 yards, distortions will be in the other direction. The width of the scope now represents 1,000 yards, and the vertical distance 2,000 yards.

20G11. Interference

Several types of interference may be encountered in the operation of the Mark 13 radar. Among these are:

Double echoes. It is possible, especially when ranging on strong echoes from nearby targets, that secondary (ghost) echoes may appear on the screen. This is due to the reflected energy from the target ship hitting the radar ship and being reflected a second time from the target ship. The operator should become familiar with this phenomenon by observing such targets on a practice run. These ghost echoes will always appear at twice the range of the original targets, and may be distinguished by observing the range of the echo and its appearance as compared to the original echo.

Shore interference. When observing shore lines, there will be a small area (generally of negligible importance with the excellent discrimination of the Mark 13 radar) in which targets may be obscured by land background.

Air targets. While this equipment is not designed for tracking aircraft and does not provide for pointing indication or measurement of elevations, the 4° vertical beam will pick up echoes from aircraft. Air targets can usually be distinguished from surface targets by their high speed and rapid fluctuations. Echoes from planes flying over land are often hidden in the land echoes. If the antenna is elevated so that the lower edge of the radar beam is barely above the land, a means might be provided for the detection of enemy aircraft approaching low over the land. A plane flying 2° (half-beam height) above the land would produce an echo on the screen. Ranges and bearings (but not elevation angles) would thus be obtained. Because of this good discrimination in elevation, warning of approaching planes can be obtained when it might not be possible with other equipments. An 11.5° sector can be covered by each Radar Equipment Mark 13 without movement of the gun directors.

Minor lobes and nearby objects. The power from the antenna radiated in the minor lobes is small compared with that in the major lobe. Nonetheless, minor lobes may cause echoes from a large target close to the equipment. In a horizontal line across the screen will be one bright echo and several dimmer ones. It is characteristic of minor-lobe echoes that they all will be at exactly the same range and will fluctuate together with the main echo.

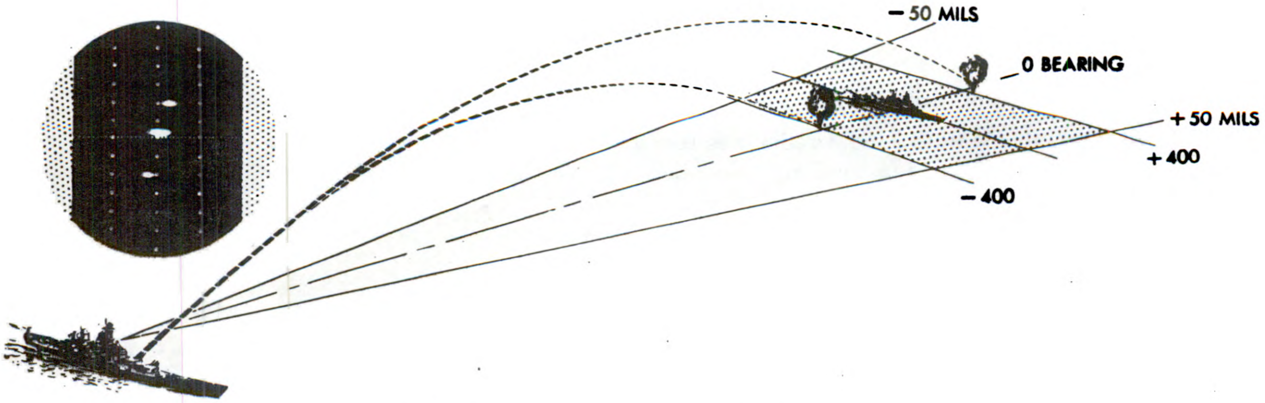


FIGURE 20G17.—Appearance of splash echoes on scope.

A small target with poor reflecting surface at close range may also send back weak echoes. It is therefore possible that, if a strong echo and one or more weak echoes are observed at exactly the same range, it may be assumed that the minor lobes cause the weaker signal. Careful checks should be made to prevent misinterpretation of such an occurrence.

Interference from other radars. Other radars operating in the vicinity may produce a background noise on the scope which will not, in general, affect operation.

Sea return. At times, particularly in stormy weather, large, irregular, and fluctuating pips may appear on the screen. This is called *sea return,* and is caused by echoes from waves. Reducing the receiver gain will eliminate much of the sea return and tend to sharpen the outlines of the target echoes.

20G12. Spotting

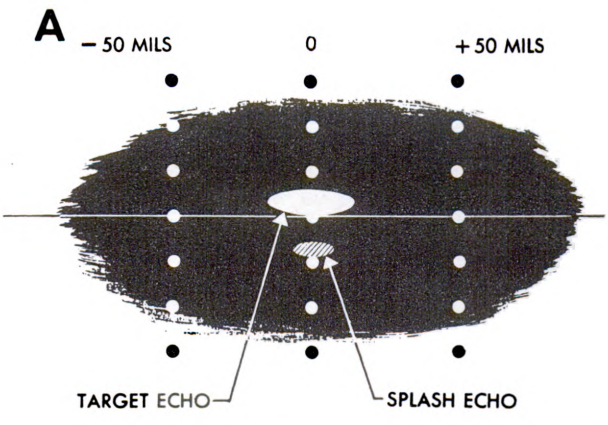
The Mark 13 radar can be effectively used to spot fall of shot in both range and deflection. Shell splashes appear on the B-scope as fluctuating echoes which last for several seconds, depending upon the size of the projectile and the range. Salvos produce larger or multiple echoes on the scope. Radar spotting has proved to be both accurate and reliable to the full range of the guns and is, of course, independent of visibility conditions. In using the B-scope for spotting, precision sweep gives the best indications of shell splashes and is normally used.

For best results, accurate tracking with the target echo kept adjacent to the range line and bisected by the center bearing line is essential. The error of the MPI from the target echo can then be easily estimated, using the dots on the bearing line, which are 200 yards apart, as a yardstick in range. It is also helpful in deflection spotting to keep in mind that the average width of the splash echo may be taken as approximately 18 mils. Figures 20G17 and 20G18 give examples of splash echoes as they would appear on the scope for various range and deflection errors.

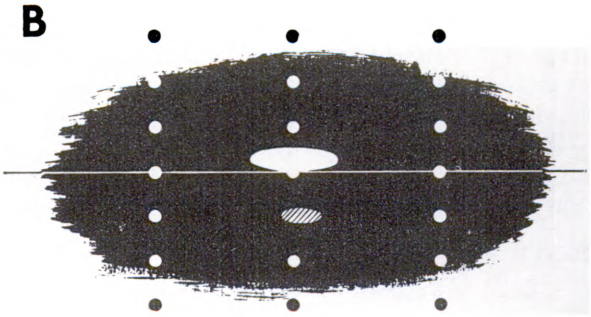
20G13. Radar Equipment Mark 8 Mod 3

As stated earlier, the Mark 8 Mod 3 radar was the predecessor of the Mark 13 radar and may still be found in some ships. Since this radar is very similar to the Mark 13, both in construction and in operation, only the major differences are pointed out here:

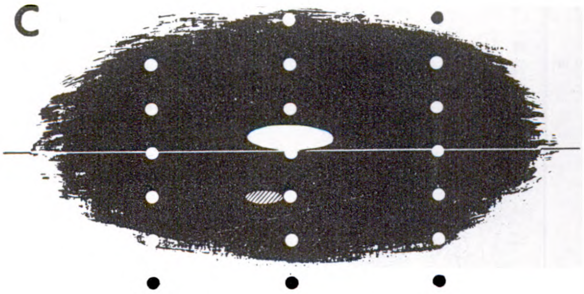
1. Packaging of the equipment is not as compact nor as easily accessible for maintenance.
2. There is only one range line.
3. On main sweep, the operator can view to 60,000 yards, but can measure range only to 44,000 yards.



ZERO DEFLECTION ERROR



ERROR — 3 MILS RIGHT



ERROR — 9 MILS LEFT

Figure 20G18.—Deflection spotting.

4. It has three sweeps instead of two: main sweep, 0 to 44,000 yards; expanded sweep, 0 to 20,000 yards; and precision sweep, any 2,000 yards out to 44,000 yards.
5. All bearing lines are solid.

Chapter 21

BATTERY ALIGNMENT

A. Alignment of Gun Sights

21A1. Introduction

No matter how well the elements of a gun battery and fire control system function individually, they cannot function as a system unless they are properly aligned with each other. Battery alignment is the process of aligning all instruments and guns to a common system of reference points, lines, and planes. This process ensures that all associated gun bores, lines of sight, radar beams, *etc.*, are parallel where the dials are matched, when no parallax or ballistic corrections have been made. It ensures further that they remain parallel throughout their operating motions, and that all instrument dials and automatic control equipment measure these motions correctly with respect to the proper reference.

21A2. Alignment of sights

The initial step in battery alignment is to fix the relation of the optical line of sight (LOS) through the gun sights to the axis of the bore of the gun. This is essential if there is no fire control system and the gun sight is used to point the gun. If a fire control system is involved, gun-sight alignment is also the first step in battery alignment, since some of the other elements of the system will, for convenience, sometimes be checked to the gun sights instead of directly to the gun bores. Before proceeding with the detailed discussion of how gun sights are aligned, the student is advised to review the description of gun sights in chapters 6 and 16.

21A3. Requirements

Gun-sight alignment procedure is planned to meet certain requirements, as follows:

1. The pointer's and trainer's telescope do not lie in the axis of the bore. For firing at short ranges in local control they must, therefore, be aligned so that their sighting axes converge with the extension of the bore axis at the target. Since, however, the gun bore is only a few feet from the sights, the error which may be caused by parallel alignment is very small. Thus, for battle use gun sights may be aligned either to *mean battle range* for the battery involved or along parallel lines (converging at infinity). This process is called *boresighting.*

2. The values of sight angle and sight deflection must not contain inaccuracies due to lost motion in the sight mechanism.

3. Elevation or range setting must elevate or depress the sighting axis of the telescopes in a plane perpendicular to the trunnion axes, and deflection setting must move the sighting axes of the telescopes in a plane parallel to the trunnion axes; in other words the sights must be aligned for parallelism.

21A4. Boresighting

The object of boresighting is to establish either (1) convergence of the sight axes and the bore axis at a specified distance, or (2) parallelism of these axes, *with the range scale and the deflection scale reading their zero value in each case.*

In order to adjust the sights in this manner, use must be made of a boresight telescope. This is a telescope which may be mounted in the bore of a gun and adjusted so that its line of sight coincides with the axis of the bore. Then by sighting through this telescope and through the sight telescopes simultaneously, the latter may be adjusted to obtain convergence or parallelism.

There are two main types of boresights: the *breech-bar boresight* and the *boresight with self-contained optics.*

A breech-bar boresight consists of (1) a *boresight telescope,* (2) an *adapter* for installing the telescope in the gun, and (3) a *muzzle disc* used for aligning the telescope on the axis of the bore. With bag-type guns, the adapter takes the form of a *breech bar* that can be installed across the screw box. A breech-bar boresight can also be used for boresighting a 5"/38 gun, but with a different type of adapter. The same boresight telescope can be used in boresighting all guns from 5-inch to 16-inch caliber (except the dual-

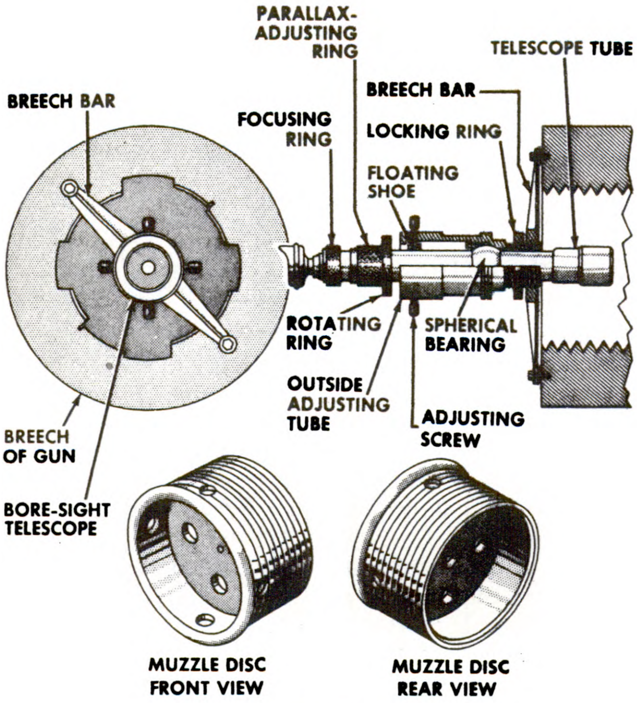


FIGURE 21A1.—Boresight apparatus.

purpose 6″/47 and the rapid-fire 8″/55), if provided with the proper adapters and muzzle discs.

Boresights with self-contained optics vary in construction and even in principle of operation, from those that consist merely of a fitting with a small hole for the breech end and another with a pair of crosswires at the muzzle end, to those that convert the gun into a huge (but low-power) telescope. Self-contained optics boresights are made to fit only the guns for which they are designed. No parts of them are interchangeable between guns.

The boresighting process with either major type of boresight is substantially similar, except that breech-bar boresight telescopes must first be aligned on the gun bore axis by sighting on the muzzle disc. This step is not necessary when using boresights with self-contained optics. This section describes boresighting with a breech-bar boresight, which requires this extra operation.

21A5. Boresight apparatus (breech-bar type)

The equipment required at the gun to boresight a bag gun includes, as noted in the preceding article, a breech bar, a boresight telescope, and a muzzle disc. The equipment and method of mounting on a gun are shown in figure 21A1.

The breech bar is a precision-machined bar which can be attached to the face of the breech by two screws. There is a hole through the midsection to receive the outer tube of the boresight telescope.

The boresight telescope tube is mounted within an outside adjusting tube which screws into the breech bar and is locked by means of the locking ring. Within the adjusting tube, the telescope is mounted in a spherical bearing which permits the telescope to be adjusted in both the horizontal and the vertical plane by means of four adjusting screws, so that the axis of the telescope has three rings near the eyepiece: (1) the reticle focusing ring for focusing the eyepiece to the individual eye, (2) the objective focusing ring for focusing the telescope on the target and eliminating *parallax error* (apparent target displacement when the eye is shifted about the optical axis of the eyepiece), and (3) the rotating ring, which permits rotation of the telescope about its axis within the outer adjusting tube.

The muzzle disc is a circular casting designed to fit snugly in the muzzle of the gun. Through the center of the disc is a small hole, and around it are four larger holes, arranged as shown in figure 21A1. Etched rings around the edge of the disc provide means for fitting the disc in the muzzle perpendicular to the axis of the bore. Notches are engraved on both disc and gun as index marks. With these index marks matched, one row of holes is aligned vertically and the other horizontally with respect to the gun. The purpose of the disc is merely to assist in the alignment of the boresight telescope axis with the bore axis.

Once aligned, the muzzle disc is removed and has no further part in the boresighting of the gun until the final stage, when it is remounted for a recheck of alignment to assure that no error has crept in during the process. Boresights with self-contained optics do not require the use of a muzzle disc in obtaining alignment with the bore axis.

21A6. Boresighting preparation

The general steps necessary in getting the gun ready for boresighting are as follows:

1. See that pointer's and trainer's scopes are clear, focused, and free from parallax.
2. Remove all evident lost motion from the sight mechanism.
3. Lash back the breech plug so that motion of the ship will not swing the plug against the boresight apparatus. (For case guns, make sure that the breechblock is securely held down.)
4. Install breech bar, boresight telescope, and muzzle disc. (For boresights with self-contained optics, only the boresight components are installed. No muzzle disc or breech bar is required. Steps 5 and 6 below are also unnecessary, as is the final step in article 21A10.)
5. Focus the boresight telescope and center the crosshairs on the small center hole in the muzzle disc, using the four outer holes to align the crosshairs vertically and horizontally.

6. Remove the muzzle disc.

7. Set the range scale at zero (sight angle scale set at midpoint—usually 2000 MIN) and deflection scale at the midpoint (usually 500).

21A7. Choosing a target

A target with a clearly defined and visible *point* is suitable for boresighting in both deflection (train) and elevation. In the absence of such a target, two targets may be used: one with a clear vertical line for boresighting in deflection, and one with a clear horizontal line in elevation.

If the guns are being readied for a specific gunnery practice, the target selected should be at the range specified for that practice. For general use a target should be chosen at about the range at which the guns being boresighted are most effective, called the *mean battle range*. Or, if a parallel alignment is desired, a distant target like a star may be chosen. For elevation only, the horizon often makes an excellent target, especially for such guns as the 5-inch and 6-inch, for which it roughly corresponds to mean battle range.

21A8. Batten-board method

When a suitable target is not available, as often happens in drydock, or when it is necessary to boresight during rough or foggy weather, the batten-board method is used. It can be used either to set the sights exactly parallel to the axis of the bore, or to attain any desired angle of convergence.

A batten board is a screen set vertically on deck at any convenient distance normal to the bore axis of the gun. Marked on the batten are vertical and horizontal lines spaced at exactly the same distances that the telescopes are spaced from the gun bore(s)—these distances can be found in the Ordnance Pamphlet for the mount or turret. The markings on a batten for the 3″/50 pedestal mount are shown in figure 21A2.

If boresighting for a specified range, the separation of the lines on the batten board should be reduced. The required spacing can be readily calculated by the principle of similar triangles, as is shown in figure 21A3.

21A9. Looseness of parts and lost motion

Before beginning the actual boresighting, check for looseness of parts and for lost motion in the sight mechanism.

To check for looseness of parts, first sight on some convenient target. Then manually shake all adjustable parts, and recheck the crosshairs on the target. If the sights are off, tighten the linkage and try again. This check should be performed independently for the trainer's and pointer's telescopes.

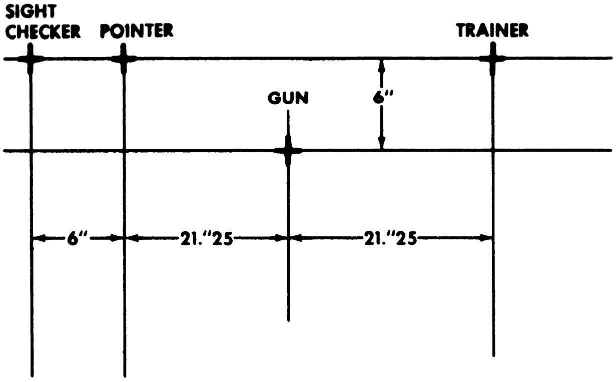


FIGURE 21A2.—Batten-board boresighting for 3″/50 mount.

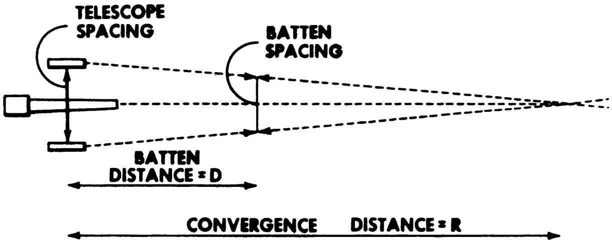


FIGURE 21A3.—Boresighting for convergence, using batten.

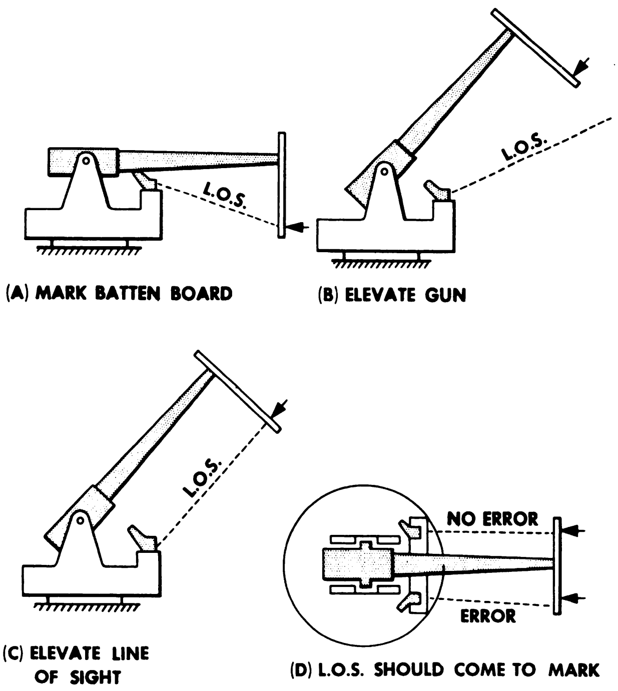
To check the sight mechanism for lost motion, set the sights so that the crosshairs are on a target whose position with respect to the gun remains fixed. Use a point on the ship itself or, if the ship is in drydock, a target outside the ship. (If the target is close to the mount, some means of removing telescope parallax, such as a focusing cap, may be required.) While this check is going on, keep the gun stationary.

Set the sights at maximum range on the range scale and then return them to their original setting. If there is no lost motion, the horizontal crosshair will return to its exact position on the target. Make a similar check for the vertical crosshair by setting maximum sight deflection, returning to original deflection setting, and observing change due to lost motion, if any.

If there is lost motion in the sight mechanism, it can be removed by taking up excessive play or clearance between moving parts.

21A10. Boresighting the gun

To boresight in train, bring the gun to bear on the target so that the vertical crosshair of the boresight telescope is aligned with a vertical mark on the target. When the boresight is on, the man at the boresight calls "Mark." If the pointer's and trainer's vertical crosshairs are not on target, adjust them until all vertical crosshairs are on at "Mark." Similarly, to boresight in elevation, align the horizontal crosshair of the boresight telescope with a horizontal mark on the target.



(A) MARK BATTEN BOARD **(B) ELEVATE GUN**

(C) ELEVATE LINE OF SIGHT **(D) L.O.S. SHOULD COME TO MARK**

FIGURE 21A4.—Checking parallelism, using attached batten.

The sight checker's telescope should also be adjusted in both deflection and elevation.

After boresighting, recheck for looseness of parts. Before securing, place the muzzle disc in the gun to make sure that the boresight line of sight is still coincident with the axis of the bore. If it is not, boresighting must be repeated.

21A11. Checking parallelism of sights

The check for parallelism is usually made while in a naval shipyard. Shipyards usually have available permanently constructed battens, similar to those used for boresighting but with the lines somewhat longer than necessary for boresighting only. A plain batten without lines can also be used, as the following procedure will show (fig. 21A4).

Secure the gun in train; install and adjust the boresight; and set the sight scales at zero range (no sight angle) and no deflection. Mark the points near the bottom of the batten where the lines from the boresight and the gun-sight telescopes appear to intersect the surface of the batten board (three separate points). Next, elevate the guns and mark a point near the top of the batten where the line of sight from the boresight telescope intersects the batten.

The upper and lower points for the gun determine the elevation line of the gun; run a fine piano wire between the pair of points to represent this line. From the lower points established by the pointer's and trainer's telescopes, mark off sight lines by stringing piano wires parallel to the elevation line of the gun.

With the gun elevated near the top of the batten, the vertical crosshairs of the pointer's and trainer's telescopes should, when range is set on the sights, move down along their respective sight lines on the battens. If they do not, the sights and gun do not elevate in parallel planes.

To make a similar test for parallelism of the motion of the sight in azimuth with the boresight, spot in points on a batten as the gun is trained to establish the gun-train line. Draw a second line parallel to the gun-train line at the level of the sights. This sight-train line must be located on the same level as the sights to be checked, to keep the sight plane horizontal; otherwise, when deflection is set, the LOS will fail to follow the horizontal line, even though the sights are in correct adjustment.

To complete the check, set deflection into the sight mechanism. As deflection settings are varied, the lines of sight of the telescopes should follow the sight-train line established on the batten.

For gun mounts with carriage-type gun sights an easier method of checking for parallelism utilizes a small batten board attached to the gun muzzle(s). With this board attached, start with the gun near zero elevation. Depress the sights by setting in some sight angle, and mark the points on the board where the lines of sight of each telescope meet it. Now elevate the gun. This will cause the lines of sight to move off the marks. If the sight trunnions and the gun trunnions are truly parallel, it should be possible to bring the lines of sight back on the marks by use of the *sight-angle* crank only. If there is an error, it can be measured by using the sight-deflection adjustment to get back on the marks.

B. Train Alignment in Drydock

21B1. Train alignment in drydock

The alignment of ship's battery involves (1) the mechanical alignment of the parts making up each element, and (2) the alignment of the various elements with one another. Alignment of parts within an element is largely a matter of design and installation; however, the gunnery officer should be able to check this alignment, and assure himself that it is accurate. Alignment of the various elements with one another is a primary concern of the gunnery officer, who should be familiar with methods employed in

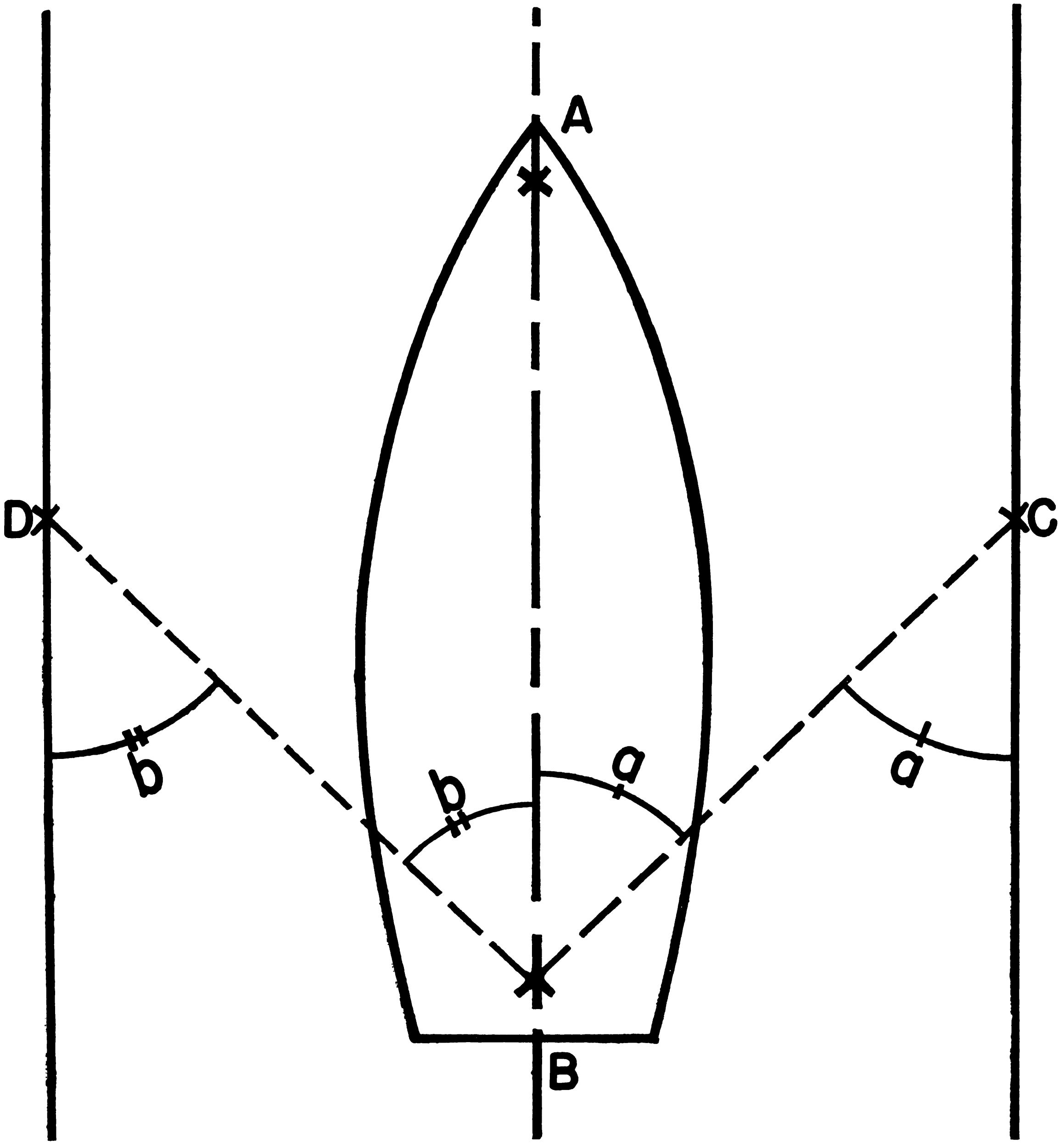


Figure 21B1.—One method of establishing an offset centerline.

effecting the original alignment (in drydock), and should be able to make provision for routine checking and adjustment of the alignment when at sea.

Space limitations will not permit full discussion of all alignment procedures applicable to specific installations, for these installations are many and varied. The following discussion is limited to general procedures and principles used for batteries of 5-inch guns or larger, without reference to particular systems.

21B2. Preliminary work

Before proceeding with the alignment it is desirable to check the synchro transmission system to assure (1) that various transmitters are sending out a correct electrical signal for a given mechanical input, and (2) that receivers are converting this electrical signal into a mechanical motion equal to that of the transmitters. It is first necessary to set the synchros to electrical zero. Any of several methods may be used, and each synchro dial should read zero when that synchro is on electrical zero. The next step is to check transmission, which is accomplished as follows:

1. Man the telephones at the stations to be tested.
2. Set the switchboard in turn to transmit from:
   a. The directors to Plot.
   b. Plot to the guns.
   c. The directors to the guns directly (by-passing the rangekeeper or computer).
   d. The stable element to the directors (to transmit level and crosslevel).

3. Turn the transmitter to various readings, usually in 10° increments throughout its operating range, and compare the receiver readings with the transmitted values. They should check exactly. Any errors of position, direction, or firmness of position should be investigated by standard synchro methods. Particular attention should be paid to the action of the receiver dials when coming to rest. They should stop quickly and evenly in agreement, and there should be neither sluggishness nor long oscillation.

21B3. Establishing an offset centerline

The purpose of the train alignment is to adjust the battery so that the lines of sight of directors and guns and axes of gun bores are parallel (in the horizontal sense) at all angles of train, when no ballistics or horizontal parallax are considered and the dials are matched. This is accomplished initially by aligning each element to the centerline of the ship, which is the line of 0° train. But the centerline itself cannot be used for alignment because of ship's structures in the way. Therefore, the first step is to establish an *offset centerline*. This is normally a line on shore which is parallel to the centerline of the ship.

The offset centerline is usually determined and definitely marked by the yard force. However, it is well for the gunnery officer or a representative of his department to check with the yard throughout the whole procedure.

The transit, which is an instrument employed in surveying, is used in establishing the offset centerline and for other steps in battery alignment. The instrument makes possible accurate measurement of horizontal and vertical angles. Though transits vary in details of construction, the basic principles are always the same. A plate with a graduated circle, or azimuth scale, is carried on a tripod support. This plate can be positioned in a true horizontal plane by means of levels and adjusting screws fitted to it. A separate plate, which can be rotated in the horizontal plane, concentric with the azimuth plate, supports a telescope. The telescope is mounted in bearings which allow movements in a vertical plane also, and therefore permit measurement of vertical angles.

To measure horizontal angles, the telescope plate is moved until its zero mark is lined up with the zero mark of the azimuth plate. It is then clamped to the azimuth plate in this position. The two plates are then rotated together until the telescope crosshairs line up with a distant point on the reference line being

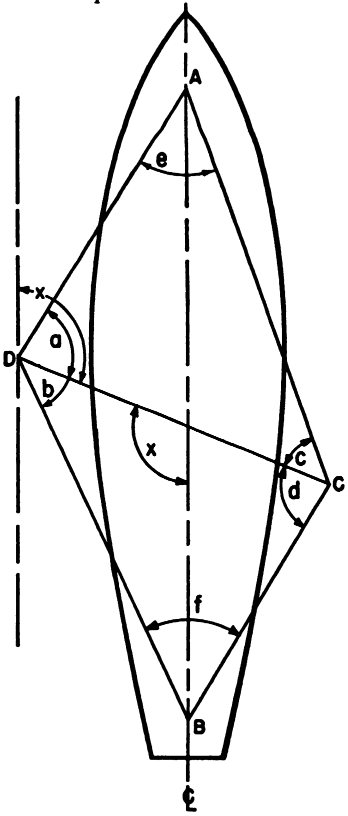


Figure 21B2.—Alternate method of establishing an offset centerline.

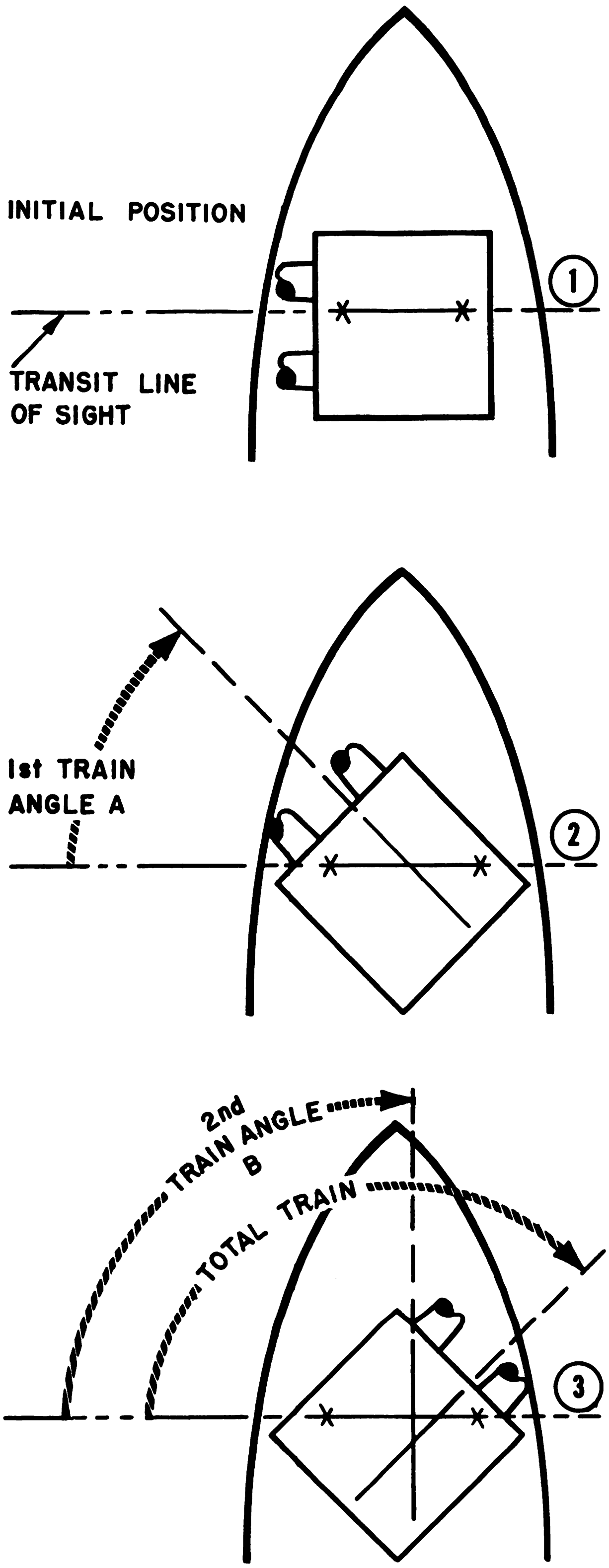


FIGURE 21B3.—Establishing the center of rotation, less than 180°, first step.

established. A plumb bob on the instrument locates the transit on the reference line at the vertex of the angle being measured. If the azimuth plate is now clamped to the support and the telescope plate is unclamped, angles can be measured from the established reference line at the chosen vertex point. Both the scale for reading these angles and the one for reading the vertical angles are usually equipped with vernier adjustments which permit readings to fractions of a minute of arc.

If there can be found on the actual centerline of the ship two points which are visible from each other, the procedure which follows is quite simple (refer to fig. 21B1).

1. Set up a transit over B, one of the points on the centerline. Lock the telescope plate at the zero point on the azimuth scale and sight on the other point, A, on the centerline. Clamp the azimuth plate to the transit support.
2. Select some other point on shore through which the offset centerline is to be established, such as C or D, depending on which side of the ship the line is to be located. Unclamp the telescope plate from the azimuth plate and sight on either point C or D. Read and record the corresponding angle, *a* or *b*.
3. Then set up transit at C or D. With the telescope set on zero azimuth and locked, sight back on B. Lock the azimuth plate at this position. Then release the telescope plate, set it an angle *a* or *b* as appropriate, and lock. The transit telescope is now pointed parallel to the centerline of the ship.
4. Establish other points in the offset centerline by setting up stakes in the line of sight of the transit.

If no two points can be found on the ship's centerline which are visible from each other, the following method must be employed;

1. Select two points, one on either side of the ship (C and D), which can be seen from each other and also from two points on the centerline (A and B). (See fig. 21B2.)
2. Set up the transit over A, B, C, and D in turn, and measure angles *a, b, c, d, e,* and *f*.
3. The value of angle *x* may then be computed, using the data obtained in step 2. The following formula may be used in making this computation:

$$x=\text{arc tan}\,\frac{\sin a \sin c \sin f+\sin b \sin e \sin d}{\cos a \sin c \sin f-\cos b \sin e \sin d}.$$

Work sheets are available which simplify the computation of angle *x* by logarithms.

4. Set up the transit over D and sight on C. Rotate the telescope plate through the angle *x*, and the telescope is then parallel to the centerline of the ship. Other points on the offset centerline may now be established as in the preceding method.

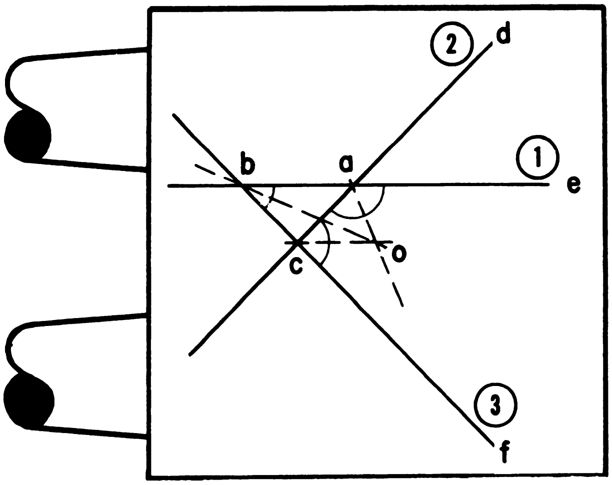


FIGURE 21B4.—Establishing center of rotation when total train angle is less than 180°, second step.

21B4. Establishing the center of rotation

It is also necessary to establish the center of rotation of each battery element, so that a transit may be set up over a given center of rotation to measure the true angle of train of the mount or director in question. A center of rotation may be located by using either the transit or the plumb-bob method.

In the transit method, a transit is set up (on ship or ashore) at a point from which the top of the shield or mount can be seen. If the mount is of the open type, it is necessary to build a platform on which lines to determine the center of rotation can be drawn. The platform will also be needed later to support a transit at this point. With a helper stationed on the mount, sight on its estimated center of rotation and lock all motions of the transit. On top of the mount locate two points in the transit line of sight and draw a line connecting these two points. Then train the mount through two different angles, and in each case draw a line on the mount top through the transit's line of sight (see fig. 21B3).

Case 1: Sum of two train angles is *less* than 180°. In figure 21B4, the three original lines on the mount top are designated as 1, 2, and 3. Draw the bisector of the interior angle of the triangle formed by the first and third lines. In the figure this is *ob,* the bisector of angle *cba*. Next draw the bisector of the exterior angle of the triangle formed by the first and second lines. In the figure this bisector is *ao,* and the angle is *cae*. Finally, draw the bisector of the exterior angle formed by the second and third lines. In the figure this bisector is *co* and the angle is *acf*. The

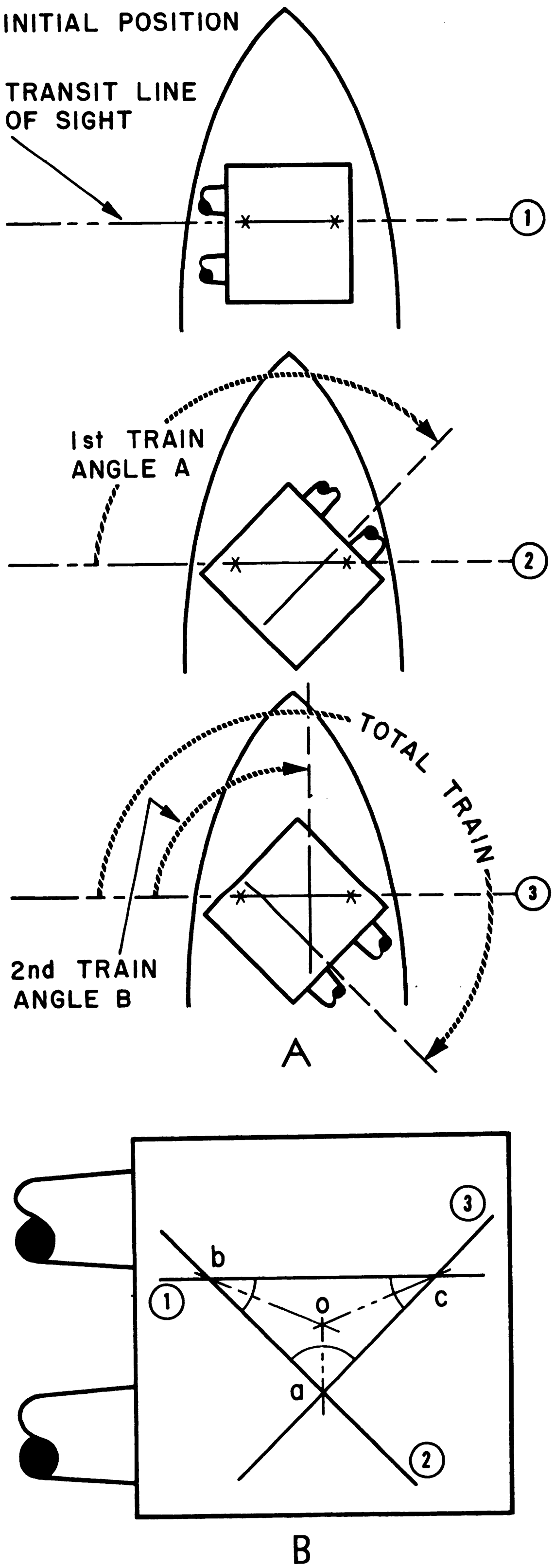


FIGURE 21B5.—Establishing center of rotation when total train angle is greater than 180 degrees.

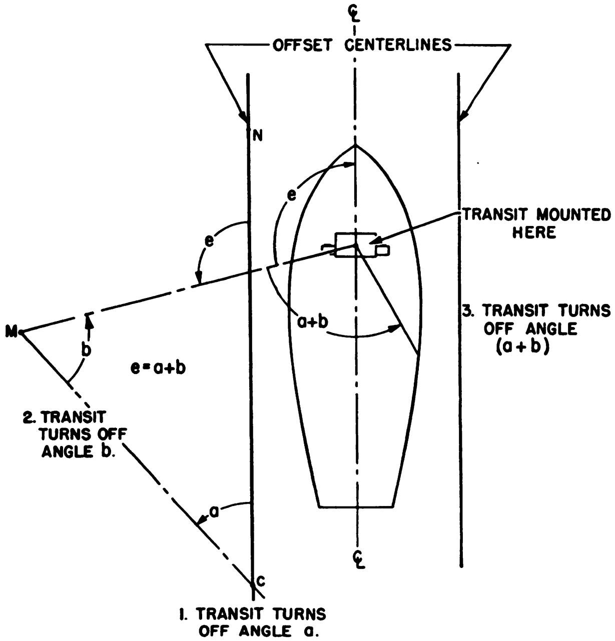

℄
OFFSET CENTERLINES
N
e
e
TRANSIT MOUNTED HERE
3. TRANSIT TURNS OFF ANGLE (a+b)
a+b
M
b
e=a+b
2. TRANSIT TURNS OFF ANGLE b.
a
℄
C
1. TRANSIT TURNS OFF ANGLE a.

FIGURE 21B6.—Establishing zero train of a director.

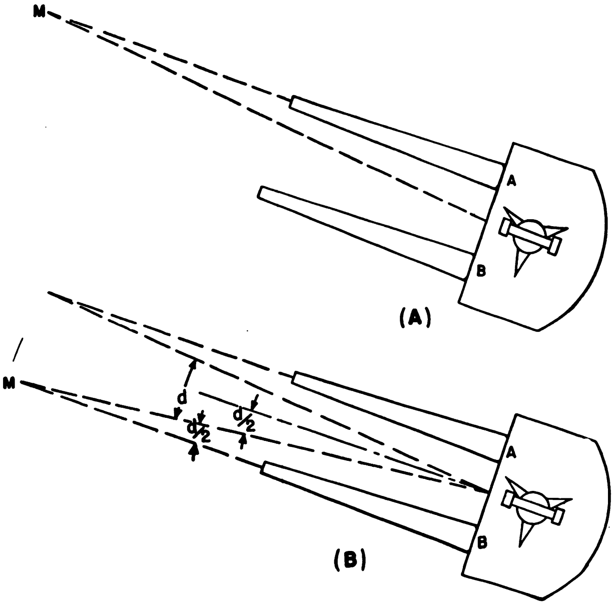


FIGURE 21B7.—Establishing zero train of a two-gun turret, first step.

intersection of these three bisectors is the center of rotation, *o*.

Case 2: Sum of the two train angles is *greater* than 180 degrees. As shown in figure 21B5, the three original lines are labeled as in Case 1. Note also that the intersection of the bisectors of each of the interior angles of the triangle is the center of rotation, *o*. In the figure these bisectors are *oa, ob,* and *oc.*

The plumb-bob method can be used if a structure not attached to the mount is available over the mount. Suspend a plumb bob from this structure so that it hangs close to the center of rotation. As the mount is trained the plumb bob will describe a circle, the center of which is the center of rotation.

After a center of rotation has been determined, it should be checked by sighting from a transit to assure that this calculated center does not move out of the transit line of sight when the mount is trained. The center of rotation should then be permanently marked for future use.

21B5. Establishing zero train—director

The first step in effecting actual alignment in train is the establishment of zero train; that is, setting the train dials of each element so that when these dials read zero train the line of sight or bore axis of the element in question is parallel to the centerline of the ship and pointing forward. Zero train of a director is established as follows:

1. Select some point on shore (M in fig. 21B6) from which the director and some point (C) on the offset centerline can both be seen. This point (M) is the reference point, and will be used for zeroing all elements that can be seen from it.
2. Set up a transit over C, lock telescope at zero on azimuth scale, and sight forward along the offset centerline at some point (N). Lock the azimuth plate movement, release the telescope plate, and sight on M. Read and record the angle (*a*).
3. Set up a transit over M, lock the telescope at zero on azimuth scale, and sight back at C. Lock the azimuth plate, release the telescope plate, and sight on the center of rotation of the director (previously established and marked). Read and record this angle (*b*).
4. Train the director until the reference telescope (usually the pointer's), which in this discussion is considered as being located on the centerline of the director and properly aligned with all other parts of the director assembly, is sighted directly on M. Make sure that parallax is not present in the telescope, and also that no horizontal parallax is being introduced into the director dials by its parallax mechanism.
5. Set up a transit over the director's center of rotation, lock telescope at zero on azimuth scale, sight back at point M, and lock azimuth plate. Now both the transit and the reference telescope are sighted on M.
6. Study of figure 21B6 shows that the director and the transit are trained from the true fore-and-aft direction by the angle *e*. This angle (*e*) is equal to angle *a* plus angle *b*.

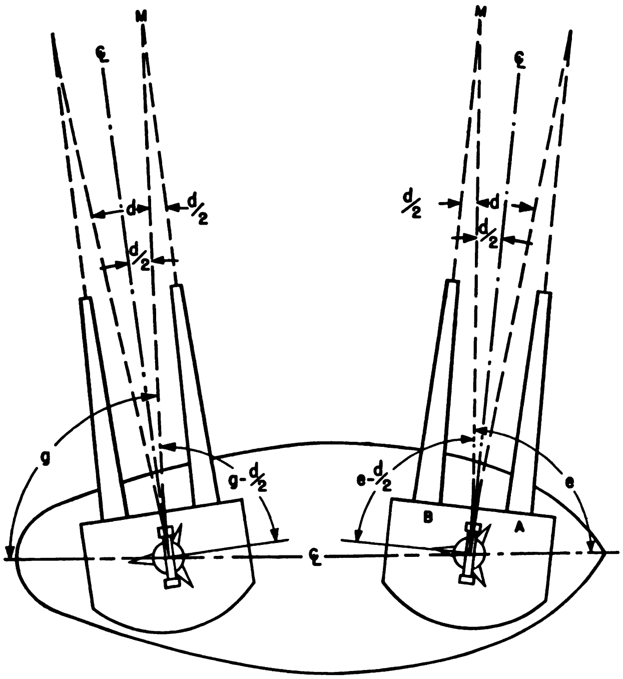


FIGURE 21B8.—Establishing zero train of a two-gun turret, second step.

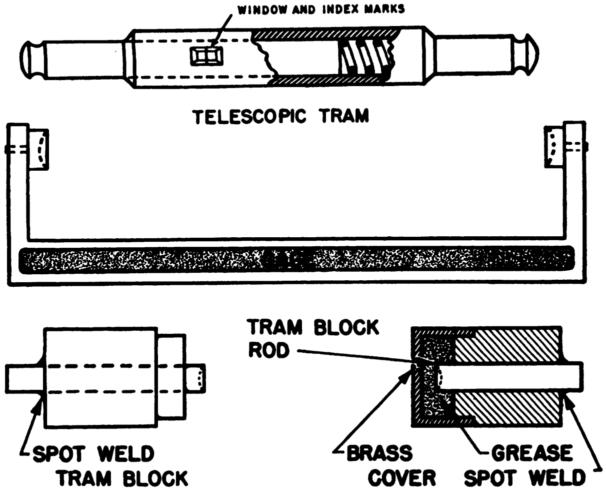


FIGURE 21B9.—Tram, tram gage, and tram blocks.

7. Release the telescope plate of the transit, and turn it aft until it reads the angle e (or $a+b$). Lock the telescope plate.

8. Now train the director forward until the transit is again on point M. Obviously, the director has been trained forward through angle e, and now is exactly parallel with the centerline of the ship. Adjust the dials until they read zero train at this point, and adjust the transmitters so that they transmit zero train.

For purposes of checking director zero train at sea, a bench mark and a bench-mark reading are established. The bench mark usually is a small brass plate with crosslines etched on it. This plate is welded to a secure part of the ship within vision of the director sights. After zero director train has been established and the dials set, train the director and put the crosswires of the pointer's telescope on the bench mark, and read the train angle-reader dials. This is the bench-mark reading which should be recorded. The same telescope must be used for obtaining all settings and readings. On multiple director installations the parallax corrector must be set for infinity—the point at which no parallax correction is entered into the train dials.

21B6. Establishing zero train—turrets

To establish zero train of a gun mount or turret, the guns (not the sights) are sighted on reference point M (see fig. 21B6). To do this, a boresight telescope is put in the barrel of a single mount, or in the middle barrel of a triple mount and sighted on M. The boresight telescope must have its line of sight at the centerline of the bore. Then a transit is set up over the center of rotation, and sighted on M to establish zero. The transit is offset the sum of a and b away from the bow, and is secured. The mount is then trained until the transit is again sighted on M. This is zero train, and the dials may be set at 0° (180° in the case of the after guns).

When a two-gun turret is at zero train, both gun bores should be parallel (within practical limits) to the centerline of the ship. Therefore, a somewhat different procedure is necessary to establish zero train, because both guns are offset from the center of the turret. The steps are as follows. Set up a transit over the turret's center of rotation and install a boresight telescope in each gun. Train the turret until gun A is sighted on reference M. Establish zero for the transit by training it on reference M. See figure 21B7 (A). Now train the turret until gun B is on M, sight the transit on M and read the angle d turned off by the transit. See figure 21B7 (B). Then $\frac{d}{2}$ is the angle at M formed by the lines of sight of the transit and gun B. Starting with the transit and gun B trained on M, turn the transit to the left through the angle equal to $e-\frac{d}{2}$ (see figure 21B8). The forward gun A could be used, but the angle in this case would be $e+\frac{d}{2}$. Then train the turret until the transit is again sighted on M, and the turret will be at zero train. The dials should then read zero. Be sure that there is no parallax input to the turret and dials. In the case of the after turret (fig. 24B8) the angle turned toward the bow by the transit is $g-\frac{d}{2}$; then the turret is trained aft until the transit is on M again. Dials should read 180 degrees.

21B7. Trams and tram marks

A reference point for each turret or mount must be established in order to check gun train at sea. Since very few guns can depress enough to point at a bench mark on the deck, a different type of reference is used. Such a reference is established when two marks or blocks, one on the fixed portion of the mount and one on the movable portion, are a definite distance apart when the mount is at a known angle. At any future time the mount can be trained until these two marks are separated by the specified distance, whereupon the mount will be at the previously established angle and the train dial reading may be checked. The distance between the two marks is established by a *tram*, and the marks or blocks are known as *tram marks* or *tram blocks*.

Trams are of two types: the older nontelescopic, and the newer telescopic. The nontelescopic tram consists of a single piece of steel with an offset machined point at each end. These points are aligned with the tram marks to establish the predetermined angle.

The telescopic tram (see fig. 21B9) consists of an outer tube within which slides a separate bar. Motion of the bar into the tube is resisted by a coil spring carried in the latter part. As shown in the figure a small window with an index mark is cut in the tube. Another index mark on the bar can be viewed through the window. When the marks on tube and bar line up, the tram is properly set for checking dial readings. This is done by inserting the tram between two tram blocks and training the mount until the index marks line up. The turret train dials should then read the value of actual turret train, which was determined at the last check of zero train in drydock. The tram can be checked by inserting it in the gage. If the scribe marks line up, it is correct.

A number of methods are used to effect initial establishment of the tram blocks, only one of which will be described here. The mount is set at a known angle of train (0° or 180° if possible), using transit methods. Then the tram blocks are welded in place—one on the moving portion of the mount and one on the fixed portion—the approximate length of the tram apart. The tram is then inserted, and the sliding or threaded tram-block rods, which pass through the tram blocks as shown, are adjusted until the scribe marks on the tram are aligned, whereupon such adjustable members are spot-welded or peened. The angle of the mount's train is then inscribed on the tram-box plate and entered in the battery logs for future checking.

21B8. Dial accuracy check

A dial accuracy check in train is made to determine whether the dials show the actual position of the mount. During this test the parallax input should be zero. The procedure is as follows:

1. Select a fairly distant point with a good vertical edge for a target.
2. Set up a transit over the center of rotation.
3. Train the director or mount to zero train.
4. Lock telescope at zero on the azimuth scale; sight the transit on the target and lock.
5. Train the mount 10° by the angle-reader dial. Always come up to, but never pass, the desired mark on the dial.
6. Turn the transit back on the target; read and record the actual angle turned, which should be 10 degrees.
7. Train the mount to 20° by the angle-reader dial.
8. Turn the transit back on the target and read from the transit the angle trained, which also should be 10° (total transit reading 20°).
9. Continue the foregoing procedure for 360° (or to the limit of train) and then repeat in the opposite direction for 360° (or to the limit of train) to check for lost motion.

C. Elevation Alignment in Drydock

21C1. Purpose of alignment in elevation

A battery is aligned in elevation after it has been aligned in train. The purpose of alignment in elevation is to adjust the battery so that at any angle of train and elevation the lines of sight of directors and guns and the bore axes will all be elevated at exactly the same angle above a common reference plane, provided that no vertical parallax is introduced, no ballistics are considered, and the dials are matched. Before undertaking elevation alignment, each element involved should be properly adjusted, and a transmission check should be completed satisfactorily.

There is an appreciable change in the shape of a vessel between drydocked and afloat conditions.[1] While

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[1] Battery alignment is usually done with just enough water pumped out of the drydock so that the hull rests firmly on the blocks; this condition is known as *partially waterborne*.

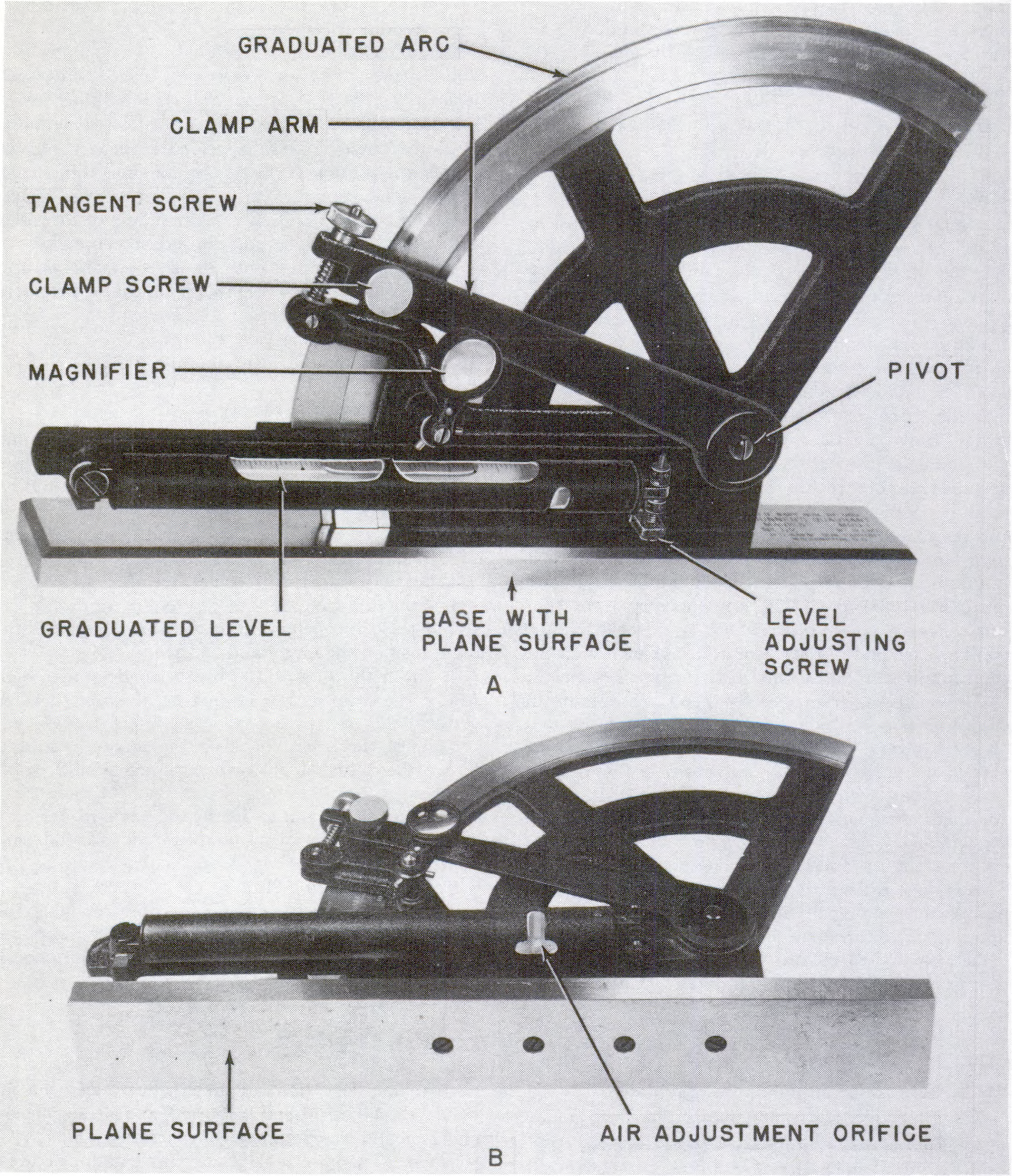


FIGURE 21C1.—Gunner's quadrant Mark 3 Mod 1 (vernier scale type).

the taking of elevation alignment data when the ship is in drydock is described here, these data cannot be used to effect a final operating alignment afloat, because of the change in the shape of the ship and the consequent shifting of the relative positions of the various elements of the battery. Therefore the battery must be realigned when the ship is waterborne.

21C2. Gunner's quadrant

To obtain data for elevation alignment, use must be made of a gunner's quadrant. The correct use and reading of a gunner's quadrant are rather difficult; accurate results can be obtained only after considerable practice. The following suggestions will prove helpful:

1. When using the quadrant, see that it rests firmly on a smooth surface, but do not clamp it to the surface so tightly that the quadrant becomes distorted.
2. Make sure the arc of the quadrant is properly positioned; *e. g.*, if the elevation of a gun at a given bearing is to be measured, place the quadrant so that its arc is parallel to or coincides with the vertical plane through the axis of the bore.
3. Bring the bubble approximately to the center by sliding the arm along the arc; then clamp the arm.
4. Center the bubble carefully by means of the fine adjustment screw, allowing sufficient time for it to come to rest.
5. In any series of observations have one man use the quadrant for the entire set of readings.

Two types of gunner's quadrants are in use at the present time: the vernier type (Mark 3 Mod 1) and the drum type (Mark 7).

The gunner's quadrant Mark 3 Mod 1 (fig. 21C1) consists of a base, the bottom of which is ground to an accurate plane surface, an arc mounted perpendicularly on the base, an arm containing a spirit level, and a clamp arm.

The level arm and clamp arm are pivoted to the arc. The clamp arm serves to secure the level at any particular position on the arc by means of the clamp screw. The clamp arm is connected to the level arm by a tangent screw for making fine adjustments between the clamp and the level. The level in the level arm is a slightly curved graduated glass tube filled with colored alcohol and containing an air bubble. The upper surface of the glass tube is graduated so that the bubble can be accurately centered. The level arm also carries the vernier scale, which slides along the arc, and a magnifier glass.

The glass vial containing the spirit level is enclosed in a metal tube with only five inches of its upper surface exposed. The glass is graduated in units of ten seconds (10″) of arc.

The main scale is 100° long, and its smallest graduation (fig. 21C2) is 15 minutes (15′) of arc. (In some mods, the degrees are divided into six parts of 10 minutes of arc each.) Each main division of the vernier scale represents 5 minutes, and the next smaller graduations represent minutes. The smallest graduations represent 20 seconds of arc each.

To use the gunner's quadrant, place it carefully on a flat surface parallel to the axis of the gun bore or other object to be measured, and with the quadrant pivot toward the center of rotation. Bring the level bubble approximately to the center of the bubble tube by adjusting the clamp arm and level arm positions on the arc. Tighten the clamp screw to hold the arms in position. Then turn the tangent screw slowly in the proper direction to bring the bubble exactly into the center of the tube. Then read the measured angle from the arc and vernier scales.

In reading the scale, count along graduations on the arc scale to the zero on the vernier. This will give a ROUGH reading in degrees and minutes. To get the fine reading, count from the zero on the vernier scale up to the division on the vernier scale that lines up exactly with a division on the arc scale. This will give the fine reading. Add the coarse and fine readings together to get the total angle of inclination.

In figure 21C2, the indicated value is 9° 18′ 40″ This is read as follows:

1. The zero on the vernier falls between 9 and 10 on the main scale. The smallest graduations on the main scale are ¼° or 15′ apart. Since the zero graduation on the vernier falls between the first and second small graduations above the 9° graduation (which is not visible in the detail view of figure 21C2), the coarse reading must be 9°15′.
2. Now locate the graduation on the vernier which lines up with a graduation on the main scale. (This is pointed out in the figure by the small black arrow.) Since, as the engraving on the vernier scale shows, the smallest graduations on the scale represent values 20″ apart, all that remains is to count on the vernier scale the graduations from zero to the matching one, and add this fine value to the coarse reading. This fine value is 3′ 40″. Adding this to 9° 15′ yields 9° 18′ 40″.

Often the difference between consecutive readings of a gunner's quadrant will be so small that it is not necessary to center the bubble for each reading. Instead, the second reading can be read directly in terms of the displacement of the bubble from its center position.

The Mark 7 gunner's quadrant (fig. 21C3) has been designed for easy reading. The vernier scale has been replaced by a micrometer drum mounted on the shaft of the tangent screw. For coarse adjustments, the level arm can be moved to any position by disengaging the tangent screw from the teeth cut on the arc.

The main scale is graduated as shown in figure 21C3. One revolution of the drum displaces the level

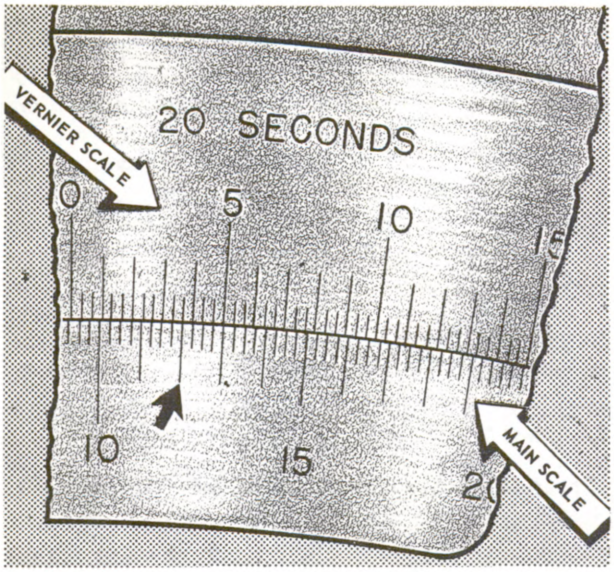


FIGURE 21C2.—Vernier scale of the gunner's quadrant.

arm by one degree. The finest graduation on the drum is 30 seconds, and each 5-minute graduation is numbered. Each graduation on the spirit level glass also represents 30 seconds of arc.

While the drum type quadrant is much easier to read, it may be inaccurate unless certain precautions are taken.

1. Lost motion often exists between the worm and worm-wheel assembly that drives the level arm. Since the fine reading is read from the drum, any lost motion of the tangent screw introduces an error—often as much as 20 seconds. However, the lost motion can be eliminated if the tangent screw is always turned in the same direction when centering the bubble.

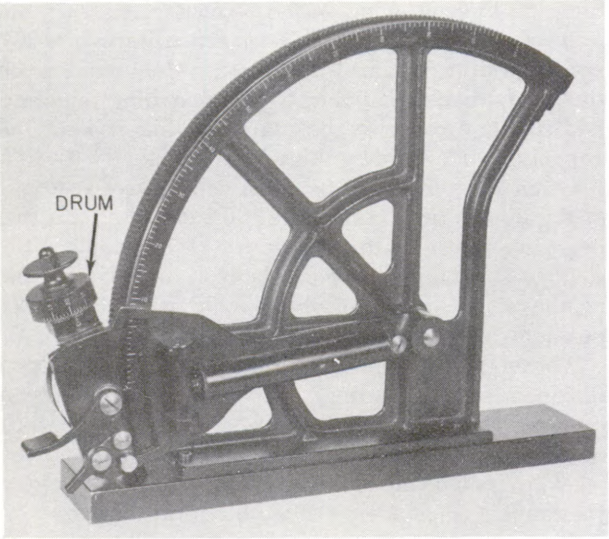


FIGURE 21C3.—Gunner's quadrant Mark 7 (drum type).

2. A second possibility for error results from inaccuracies in the teeth cut on the arc. For this reason all drum-type quadrants are calibrated and a correction sheet is issued with each quadrant. Whenever the quadrant is read, the corresponding correction factor should be applied.

3. Care must be taken in disengaging and reengaging the tangent screw. The spring holding the tangent screw against the arc is strong, and the teeth can be damaged if the tangent screw is allowed to snap into mesh.

Before the gunner's quadrant (either type) is used, it must be *zeroed,* as follows:

1. Adjust the bubble to correct length, if necessary.

2. Select a smooth plane surface that is approximately level. Place the quadrant on this surface, and draw thereon a line around the base of the quadrant. Center the bubble and read the quadrant.

3. Turn the quadrant around so that the inclination is measured in the opposite direction. Be sure that the base of the quadrant lies within the outline. Center the bubble and read the quadrant again.

4. The average of these two readings should be zero. If it is not, the quadrant must be adjusted (by the adjustment screw on the level tube) until additional tests show that the average of the two readings is zero.

21C3. Roller-path data with gunner's quadrant

A very important phase of elevation alignment is the procurement and interpretation of roller-path data. These data consist of a series of readings showing the relative inclinations of the planes of each roller path to some fixed plane. At sea this fixed plane is the reference plane of the battery, as explained in article 21C5, but in drydock it usually is a horizontal plane established by a spirit level. The data are used to determine the relationship in space of the various roller paths.

In all modern installations, it is assumed that the roller paths of all elements are true planes or so close to true planes that distortion is unimportant and not measurable. The relationship between a tilted plane and the true horizontal plane is shown in figure 21C4. It can be proved that the tilt (t) of the roller path at any point is equal to the maximum value of the tilt (T) between the planes (*i. e.,* the tilt at the *high point* of the roller path) times the cosine of the train angle (B) between the high point and the point under consideration. Therefore the readings obtained at points through the training limits of the element should vary in a sinusoidal manner, with some readings above and some below the horizontal. If they do not vary in this way, it is evident that the roller path has become distorted.

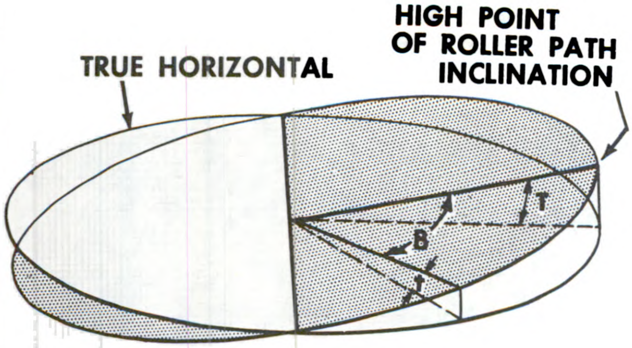


FIGURE 21C4.—Roller-path inclination.

Procedure for obtaining drydock roller-path data with a gunner's quadrant is as follows:

1. Secure the quadrant to some smooth surface on the gun or director in such manner that the line of the quadrant is parallel to the axis of the gun bore (or the director's line of sight) and the pivot of the arm is forward.
2. Set the roller-path tilt corrector (if there is one) to zero tilt.
3. Elevate the gun to some convenient angle; this will make all readings positive. The difference between the readings is all that is important, so the amount of elevation is immaterial. In the case of a director, the forward end of the quadrant must be shimmed up to obtain the same results.
4. Train the gun or the director to 0°, level the bubble, and read the quadrant. Repeat this process for every 10° or 15° of train. Record the inclination and the angle of train in each case.

21C4. Interpretation of roller-path data

The purpose of taking roller-path data is to determine the actual relationship between the roller path and the horizontal plane. Then the necessary compensations can be made for aligning all elements of the battery to a common reference.

The relationship between any roller path and the horizontal is defined by the amount of tilt at the highest point of the path and the bearing of this point, and compensating devices are built to correct in these terms. Therefore, in order to interpret the results these two quantities must be determined for each roller path.

There are two commonly used graphic methods available for this determination: the *sine-curve method* and the *60° radial method*. In order to explain these methods more clearly we shall assume a set of typical roller path data shown below, and actually find the high point and its bearing by these methods.

Although the following table shows inclination at 30° intervals of train, in actual practice, readings would be taken every 10° or 15°.

Train Angle (Bearing)	*Inclination from Horizontal*
0°	2° 30′
30°	2° 40′
60°	2° 47′
90°	2° 50′
120°	2° 47′
150°	2° 40′
180°	2° 30′
210°	2° 20′
240°	2° 13′
270°	2° 10′
300°	2° 13′
330°	2° 20′
360° (0°)	2° 30′

Note that all readings are positive. This is due to the fact that the quadrant was slightly elevated, as mentioned before, to avoid the complication of negative numbers.

Sine-curve method. As stated before, the inclinations from the horizontal will vary in a sinusoidal manner. Therefore, if the inclinations are plotted against the bearings, a sine curve will result. The curve for the sample data readings is shown in figure 21C5.

The bearings are read along the horizontal axis, and the inclinations are plotted vertically at these bearings. Then the sine curve is drawn by fairing-in a line through these points. The actual fairing-in of this curve is rather difficult, and for this reason the sine method is rarely used for drydock data.

After the curve is drawn, its zero axis is drawn in, parallel to the horizontal axis of the graph. It should pass through the curve halfway from the low to the high point, and its distance from the axis should equal the arbitrary elevation which was introduced to obtain positive readings.

To determine the inclination and bearing of the high point of the roller path it is only necessary to read the bearing and inclination of the high point of the curve. This is shown clearly on the figure. In this case the path has an inclination of 20 minutes at a bearing of 90 degrees. Note particularly that the inclination is the inclination from the *axis* of the curve itself, not from the axis of the graph.

Sixty-degree radial method. The second and most widely used method of plotting the roller path data is the 60° radial method. There are several advantages to this method. Fairing a sine curve in rectangular coordinates from roller-path data obtained as described in article 21C5 is a difficult process. Also, in many cases the arc through which the element can train is limited, so that only part of the sine curve will be obtained. In all cases of limited train the radial method, which is based on the fact that a sine curve plots as a circle in polar coordinates, is preferable;

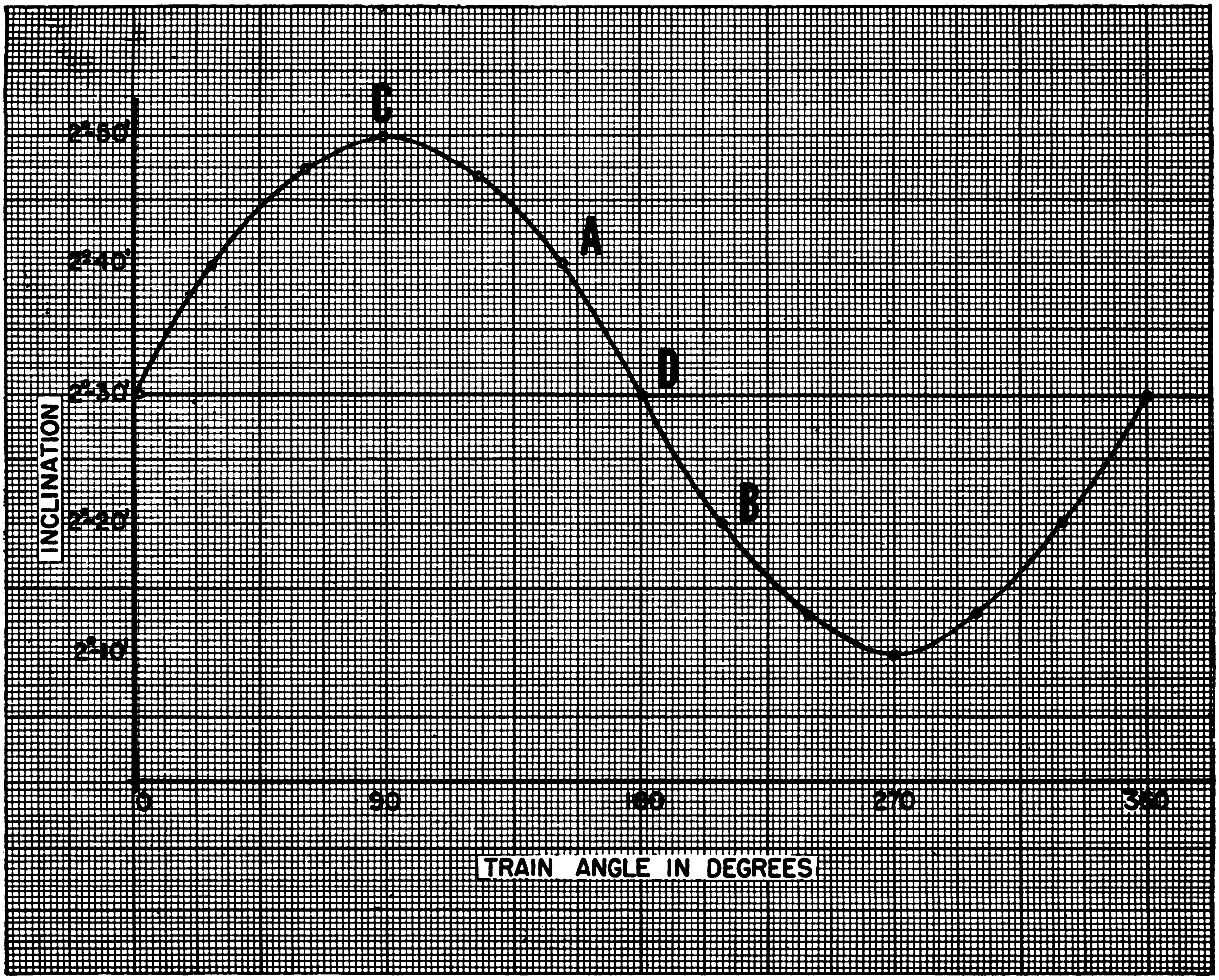


Figure 21C5.—Sine-curve method of interpreting roller-path data.

and in extreme cases it is the only possible method to use.

An examination of the sine curve in figure 21C5 will show the principle on which the 60° radial method is based. First notice the point D at which the curve crosses the zero axis. If the inclination is read at a point 30° to the left of point D (point A on the curve) the inclination can be seen to equal one-half of the inclination of the high point C. (This can be proved by trigonometry, since the sine of 30° is .5.) The value of inclination at point B, 30° to the right of point D, is also equal to one-half of the inclination of the high point C; in other words the vertical distance between A and B is equal to the total inclination at the high point C, which is the maximum inclination of the curve.

If any other two points, 60° apart, are taken, the difference between their inclinations will always be less than the maximum. Thus, if a series of readings 60° apart are subtracted from each other and differences plotted, using the median bearing, a new sine curve having the same amplitude will result, with the high point 90° from that of the original curve. To simplify the mathematics involved, instead of using the median bearing, we plot the values against the lower bearing of each pair. Now our new curve will be out of phase by only 60°, and the bearing of the high point will be obtained by subtracting 60° from that of our new curve.

Figure 21C6 shows a series of readings 60° apart arranged for plotting, with the differences indicated. The left-hand or lower bearing is used for plotting. The plot as shown is made on polar coordinate paper, and our new sine curve will appear as a circle passing through the origin. The diameter gives the maximum inclination, and 60° counterclockwise from the

INCLINATION DIAGRAM

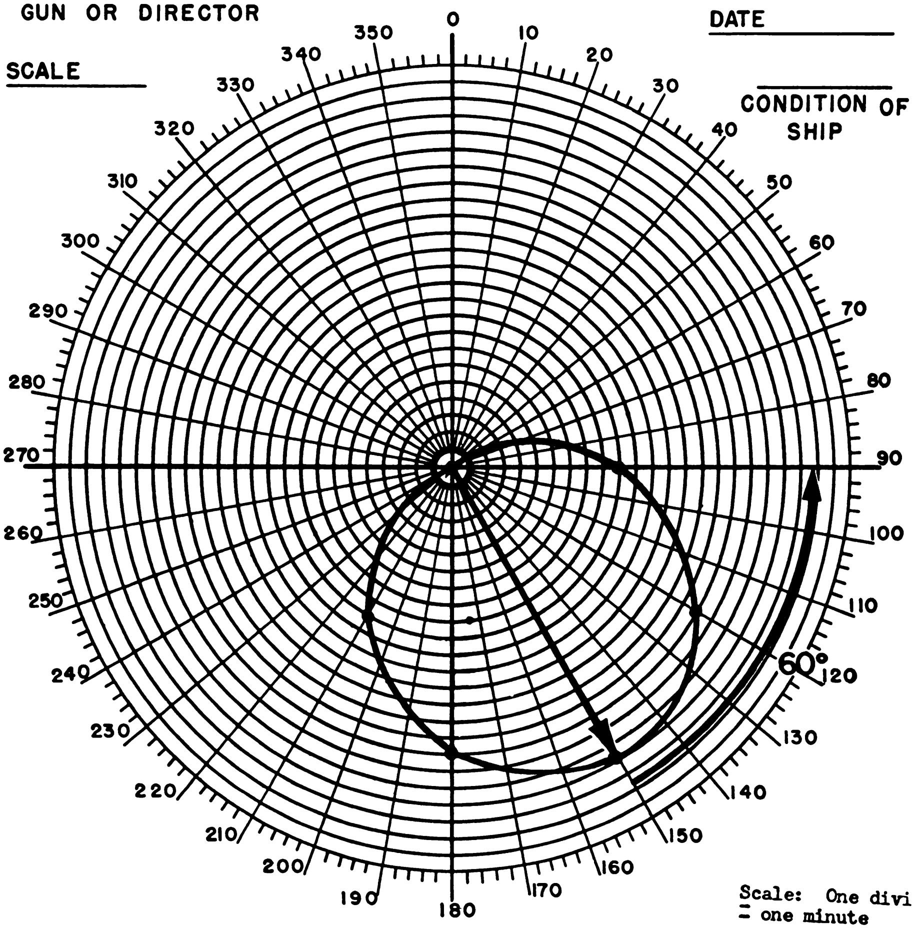
READINGS BY

GUN OR DIRECTOR

DATE

SCALE

CONDITION OF SHIP



Scale: One division = one minute

INCLINATION

BEARINGS 60° APART				BISECTOR	DIFF. OF INCLINATION	HIGH BEARING
BEARING	INCLINATION	BEARING	INCLINATION			
0	2° 30'	60	2° 47'		- 17	
30	2° 40'	90	2° 50'		- 10	
60	2° 47'	120	2° 47'		0	
90	2° 50'	150	2° 40'		10	
120	2° 47'	180	2° 30'		17	
150	2° 40'	210	2° 20'		20	
180	2° 30'	240	2° 13'		17	
210	2° 20'	270	2° 10'		10	
240	2° 13'	300	2° 13'		0	
270	2° 10'	330	2° 20'		- 10	
300	2° 13'	360 (0)	2° 30'		- 17	

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FIGURE 21C6.—Sixty-degree radial method of interpreting roller-path data.

diameter is the bearing of the high point. For the data shown, the bearing of the high point is 90° and the inclination is 20 minutes, as was obtained above in the sine-curve method. These are the settings—bearing of high point and inclination of high point—that are put on the roller-path tilt compensator.

21C5. Choosing the reference plane

The reference plane generally chosen is an actual plane on the ship; that is, it is the roller-path plane of one battery element. The plane is so chosen that the inclination between it and the roller paths of the other elements is as small as possible. On destroyers, there is only one Mark 37 director, and it is not equipped with a roller-path tilt compensator, while each of the 5-inch mounts has a compensator. The plane of the director roller path must therefore be the reference plane of the battery. If all the guns and the director were installed simultaneously, with no special consideration given to roller-path inclination (other than the usual attempt to install the elements as nearly horizontal as possible), the plane of the director roller path might vary so much with respect to one or more of the guns that it would be unsuitable as a reference plane. Therefore, destroyer guns are installed first. Then the roller-path data for each gun are taken, and the mean of all the inclinations is computed. The director foundation is machined so that its bearing surface will be as nearly parallel to this mean plane as possible.

On larger ships having more than one director, the directors (with certain exceptions) are equipped with roller-path tilt compensators. In such case the roller path of any director or gun may be chosen as a reference. At installation an attempt is made to make all paths parallel. After installation, when roller-path data have been taken, the mean plane of all elements is determined, and the roller path closest to the mean plane may be chosen as the reference plane.

The radial diagram or polar coordinate graph may be used to compute the mean plane of all roller paths, as shown in figure 21C7. In this example there are five battery elements to be considered. The bearings and inclinations of their high points are indicated in the table below the graph. Bearings and inclinations are plotted on the radial diagram, being represented by the small circles numbered 1 to 5. The sum, as indicated, is obtained by adding the various inclinations vectorially. The resultant, represented by the line drawn from the center to the end of the last line (*e*) gives the solid line (*f*) on a bearing approximately 326° with an inclination of about 16 minutes. To obtain the mean, divide the total inclination (16′) by the number of elements (5). In this case the result is 3.2 minutes. The mean of the five inclinations, then, is an inclination of 3.2′ at a bearing of 326 degrees.

On modern ships, the roller paths of the individual elements are machined very close to parallel, and almost any of them could be used as the reference plane. Present specifications require that the roller paths of the major elements be within 6′ of one another. In addition, the roller paths of the 40-mm and 3″/50 caliber gun mounts and their directors must be within 10′ of the reference plane of the dual-purpose battery so that, when the guns of one system are controlled by the director of another, excessive errors due to misalignment will not be introduced.

The final selection of the reference roller path is influenced by the obvious advantage of choosing a roller path whose inclination will be relatively unaffected by waterborne changes in the ship's structure. This consideration often dictates the choice of an element near the center of the ship, such as one of the stable elements in the plotting room, as the reference element.

After the reference plane has been chosen and its tilt is known, it is necessary to determine how much and at what bearing each of the elements is tilted with respect to this reference. The radial or polar coordinate diagram is again used for this purpose. The process involves shifting the origin of the graph so that it lies at the reference point, or what amounts to the same thing—moving all the points without disturbing their relationship until the reference point lies on the origin of the graph. Figure 21C8 shows the points of figure 21C6 transferred so that element No. 3 is the reference. The inclination of any element to this reference can be read directly from the graph. It should be noted that the lack of parallelism represented in this diagram has been assumed for purposes of illustration; such lack of parallelism is rarely encountered in modern ship construction.

21C6. Alignment of the stable element

After the reference plane of the battery has been established, it is necessary to align the stable element or stable vertical so that the plane of rotation of its sensitive element is parallel to the reference plane. Of course, if the plane of one stable element is used as a reference plane, it will still be necessary to align any additional stable elements.

The sensitive element is trained in accordance with

INCLINATION DIAGRAM

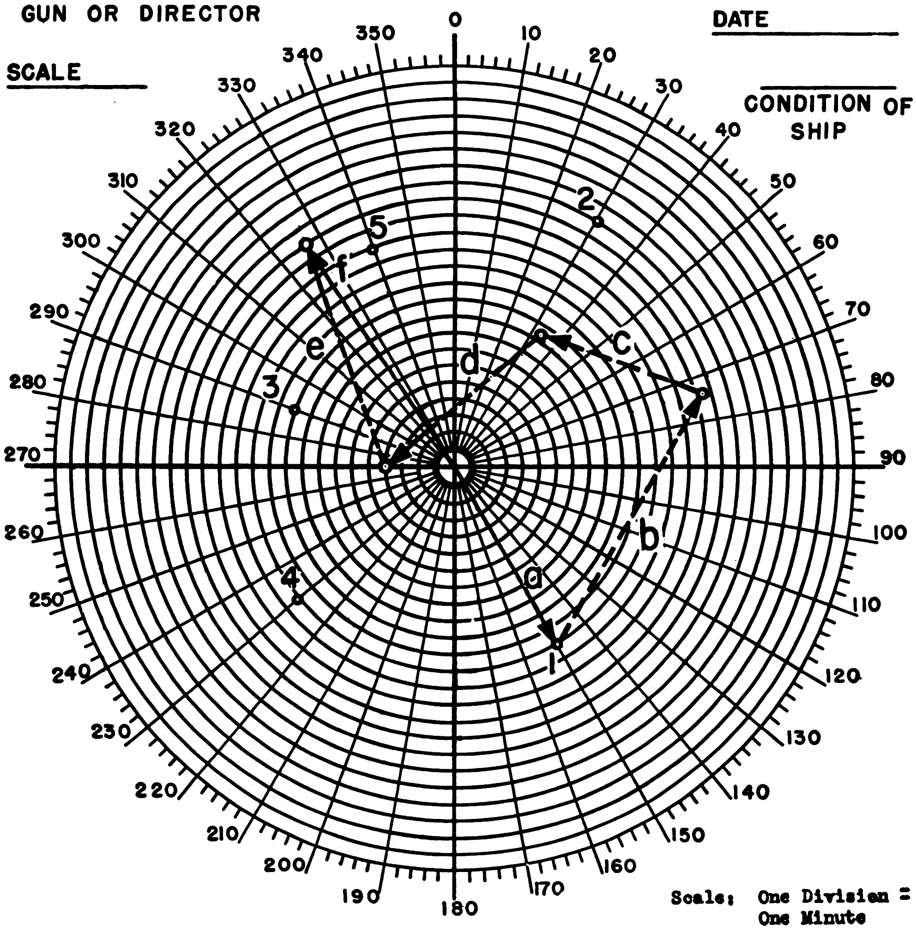
READINGS BY

GUN OR DIRECTOR

DATE

SCALE

CONDITION OF SHIP



Scale: One Division = One Minute

INCLINATION

BEARINGS APART				BISECTOR	DIFF. OF INCLINATION	HIGH BEARING
BEARING	INCLINATION	BEARING	INCLINATION			
Elem. No.	Bearing	Incl.				
1	150°	12'				
2	32°	17'				
3	290°	10'				
4	230°	12'				
5	340°	14'				

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FIGURE 21C7.—Computing the mean plane of all roller paths.

INCLINATION DIAGRAM

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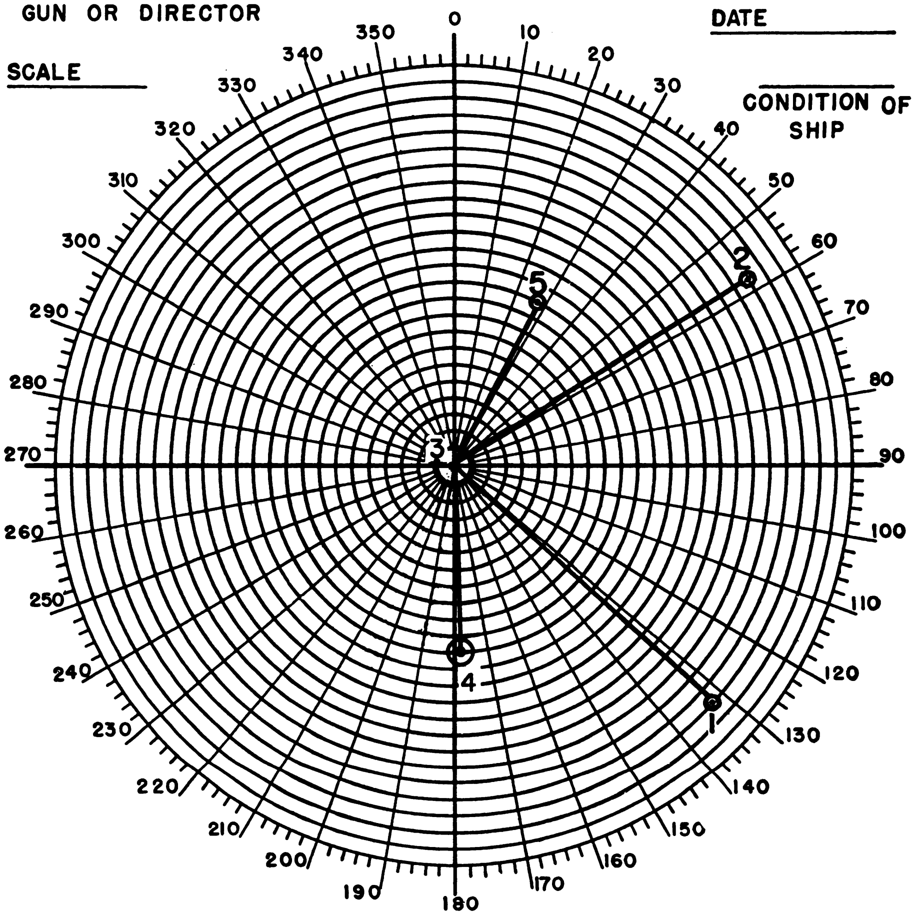
DATE

SCALE

CONDITION OF SHIP



Scale; One Division = One Minute

INCLINATION

BEARINGS APART				BISECTOR	DIFF. OF INCLINATION	HIGH BEARING
BEARING	INCLINATION	BEARING	INCLINATION			
Reference.- No. 3						
Inclination with Respect to Reference						
Elem. No.	Bearing	Incl.				
1	132°	21'				
2	58°	21'				
3	0	0				
4	179°	11'				
5	26°	11'				

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FIGURE 21C8.—Shifting reference point to origin of graph.

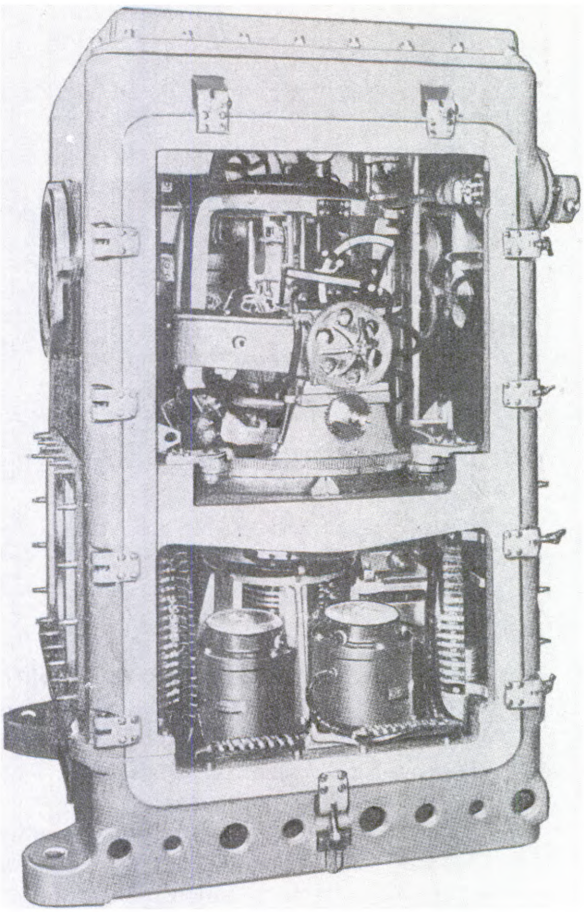


FIGURE 21C9.—Gunner's quadrant installed to check alignment of stable element.

director train and not in accordance with relative bearing in the horizontal plane. Its roller path, therefore, must be parallel to the reference plane, so that director train will produce the correct train of the stable element gimbals. Since these instruments are not equipped with roller-path tilt compensators, they must be aligned by shimming.

Two methods are available for aligning the stable element with the reference plane. Since the first of these two is invariably used with all late marks of stable elements and stable verticals, the second will not be discussed; it can be found in Bureau of Ordnance publications if required.

With modern instruments the first step is to take roller path data with a gunner's quadrant mounted on the crosslevel gimbal-mounting bracket. (See fig. 21C9.) These data are plotted in the same manner as for other battery elements, and the bearing and inclination of the high point of the stable-element roller path with respect to the reference plane are obtained.

The number, thickness, and location of the shims needed to effect alignment is determined as follows:

1. On a plain sheet of paper draw a vertical line representing the ship's centerline (see fig. 21C10). Draw a triangle, ABC, representing the three mounting legs of the stable element drawn to scale and in their correct relationship to the centerline of the ship. In the example, the scale is ⅛ *inch equals 1 inch,* and the legs are drawn so that the single leg is to starboard, as will be the case on a ship where the stable element is abaft the computer.

2. From any point O in the line representing the ship's centerline, draw a line OZ at the bearing of the high point (with respect to the reference plane) of the stable element's roller path. In the example, it is assumed that the high point is on bearing 135° and that its inclination is 15 minutes.

3. Drop a perpendicular BX, from the vertex of the triangle in the direction of the stable element's high point, to the line OZ.

4. Drop perpendiculars, AD and CE, from the other two vertices of the triangle to line BX.

5. Measure the lengths of AD and CE and convert, acording to scale, to the lengths represented. In the example, the length represented by AD is 25½ inches, and that represented by CE is 12½ inches.

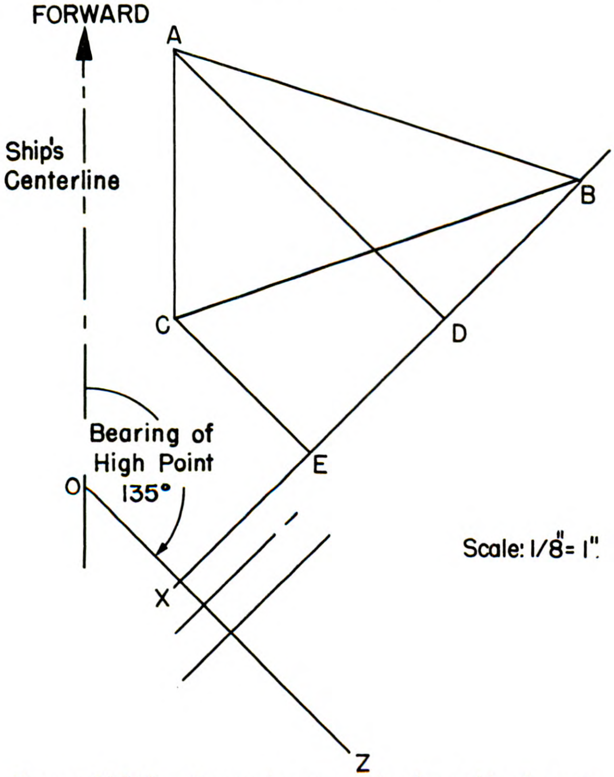


FIGURE 21C10.—Computing correction for stable element.

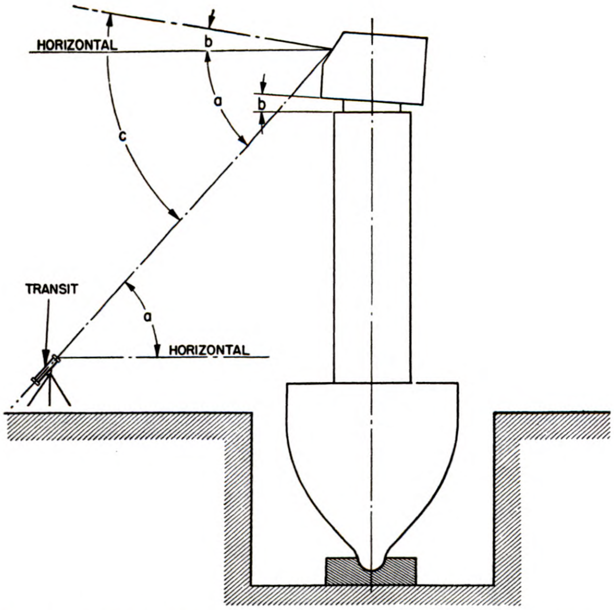


FIGURE 21C11.—Shore transit method of setting director elevation dials and establishing elevation bench marks.

6. Enter these lengths in the formula:
$S=0.0003\,LT$, in which
S is the amount of shimming needed under the leg,
L is the length represented by the line dropped from that leg in the diagram, and
T is the tilt of the roller path at its high point in minutes.

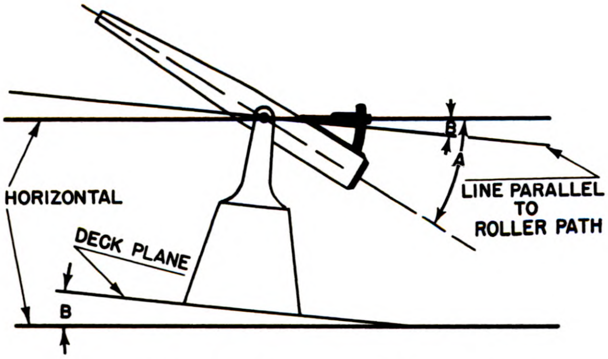


FIGURE 21C12.—Establishing elevation tram blocks.

In the example, leg A will require shims of 0.115 inch; and leg B, of 0.056 inch. Note that, in any case, only two legs will require shims.

After shims of the proper thickness have been placed, the taking of roller-path data should be repeated. If the new readings show a variation from the reference plane of as much as 2 minutes at the high point, the calculation and shimming should be repeated. (Extreme care should be exercised after the shims are inserted. The holding-down bolts are tightened evenly with a torque wrench to prevent canting the stable element.)

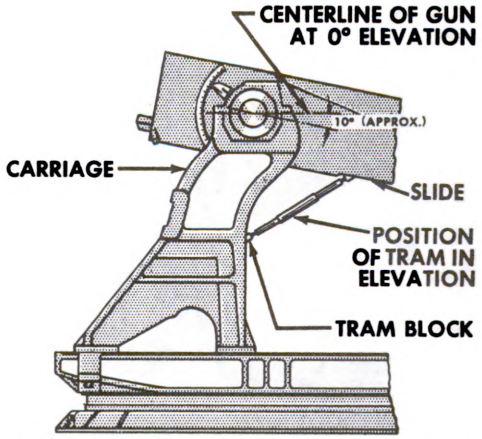

CENTERLINE OF GUN AT 0° ELEVATION
10° (APPROX.)
CARRIAGE
SLIDE
POSITION OF TRAM IN ELEVATION
TRAM BLOCK

FIGURE 21C13.—Tram mounted on 5"/38 gun for elevation reading.

21C7. Setting director elevation dials and establishing elevation bench marks

The bench mark is established to be used as a reference in checking director sights and dials at sea. The shore transit method is as follows:

1. Train the director to either the high or the low point on the roller path. This is done so that the true tilt of the director may be obtained easily from the roller-path data.
2. Vertical parallax correctors must not be operating or parallax range must be set for infinity. The roller-path compensator should be set at zero inclination.
3. Level the transit (ashore) so that the level bubble under its scope is centered when the stadia (elevation) circle reads zero. Illuminate the pointer's telescope from inside the director with a flashlight, and sight into this telescope with the transit.
4. Read angle *a*, as shown in figure 21C11. Read angle *b* from the roller-path data.
5. Depress the director telescope to sight on the transit. With the director telescope and transit aligned, read the director elevation dials. To this reading add angle *c*. Elevate the director line of sight until the elevation dials read the sum of the two. Angle *c* is equal to *a* plus *b*, which are respectively the angle below the horizontal through which the director telescope was depressed to sight on the transit, and the angle made by the director roller path with the horizontal plane. The director line of sight, therefore, will have been made parallel to the roller path, which is the condition desired. Set the elevation dials to zero with the director line of sight in this position.

6. Train the director and elevate or depress the pointer's telescope as necessary to put the crosshairs on the bench mark. Record the bench mark depression. Remember that the bench-mark readings were taken with roller-path compensator set to zero, and for future accurate checks it must be so set. To provide for quick checks with the compensator functioning, it is well to establish and record an additional bench-mark reading with the roller-path compensator set as for firing.

21C8. Setting gun elevation dials and establishing elevation tram marks

To ensure that gun elevation dials will read the true elevation above their own roller paths, it is necessary to set the dials to proper position while in drydock. This may be done in the following four ways:

1. Install a boresight telescope in the gun, and follow through the same process that was used for setting the director's dials, employing a transit set up ashore.

2. Make sure that the gun is properly boresighted, and set sight angle and deflection at zero on the gun sight. The procedure is then the same as in No. 1 except that the transit is sighted on the gun sight rather than the boresight telescope.

3. Set up a gunner's quadrant on the gun as when taking roller-path data. Train the gun to the exact angle at which roller-path inclination was read (roller-path data). Elevate the gun to any convenient angle and read the quadrant. Referring to figure 21C12, it is evident that the quadrant has read the angle A between the gun bore and the true horizontal. However, the roller path is inclined to the horizontal by the angle B. Hence, the true angle of gun elevation is $A-B$, if the roller-path inclination is positive (as in fig. 21C12) and $A+B$, if the roller-path inclination is negative. Set the dials so that they read this value of A plus or minus B, as appropriate.

4. Set up a gunner's quadrant as in No. 3. Train the gun 90° away from the high point of the roller path; thus eliminating roller-path inclination. Elevate the gun, read the quadrant, and set the dials in accordance with the quadrant reading.

After the dials have been set, the tram blocks are installed. The method used for installing train tram blocks described in article 21B7 is used for elevation tram blocks, except in the latter case one block is on the carriage and one is on the slide, as shown in figure 21C13. With the tram in position and its index marks lined up, the elevation-dial reading is recorded for use as a future check for proper elevation reading.

D. Battery Alignment Afloat

21D1. General

Since a ship is not a rigid structure, upon loading and putting to sea the space relationships between elements of a battery change, and correction for these changes must be made. The process involved is known as *battery alignment afloat,* and must be carried out while the ship is waterborne, by different procedures than those used for the original alignment in drydock.

Before initiating the actual alignment procedures, just ensure that all elements are functioning correctly and that all transmission systems are properly adjusted. Have a routine transmission check carried out just prior to the alignment check.

The purpose of afloat battery alignment in train is to ensure that:

1. When the director is trained to any point and the gun dial pointers matched, with zero settings of sight deflection and parallax, the director and gun lines of sight and the gun bore axes are parallel (in the horizontal plane).

2. When the gun dial pointers are matched, proper parallax set in, and zero settings of sight angle and sight deflection set in at the guns, the director and gun lines of sight and the gun bore axes converge on any given target at any range and on any bearing.

To accomplish No. 2 above, it is necessary to introduce parallax both into director train (in multiple director installations) and into gun train. It is therefore necessary to check the parallax system before beginning the actual alignment. Proper correction of parallax errors is important where there are a number of directors and large horizontal distances between units. Hence, all parallax correctors on guns and directors should be checked for:

1. *Correct amount* of parallax at various bearings and ranges.

2. *Correct direction* of applied parallax correction.

The purpose of afloat battery alignment in elevation is identical with the purpose of elevation alignment in drydock (article 21C1). This objective is attained by selecting some plane as the reference plane of the battery, so that the elevation of all units, when measured from that plane or a parallel plane, is equal.

21D2. Checking the directors on their bench marks

The first step in the actual battery alignment afloat is to check the directors on their bench marks. On some ships the space relationship between director and bench mark may show variations due to working of the ship in a seaway. The amplitude of this motion is usually about two or three minutes. The director should be checked on its bench mark about once a week, noting this movement. No adjustment is necessary unless checks show that the error is increasing in one direction, in which case something is wrong with the director.

The basic procedure for checking a director on its bench mark is as follows:

1. If the director uses parallax corrections, set these at zero.
2. If the director uses inputs of level and crosslevel, set these at zero.
3. Obtain the bench mark reading from the ship's records.
4. Train the director until the vertical crosswire of the pointer's telescope is on the bench mark.
5. Set proper bench mark reading on the elevation indicator dials by turning the pointer's handwheels.
6. The horizontal crosswire should now be on the bench mark. If it is not on, adjustment must be made between the elevation input to the telescope and the indicator dials until the horizontal wire is on, leaving the proper reading on the indicator dials.
7. Check the reading of the train indicator dials. It should be the bench mark reading. If not, adjust the indicator dials to read the bench mark value.

21D3. System alignment in train

After the director is on the bench mark, it is possible to proceed with actual alignment of the various battery elements. Preferably, this should be done with the ship at anchor in smooth water. If the battery has never been aligned, a complete train check must be made, but otherwise a preliminary test may be made to determine if a complete check is necessary. The preliminary test is conducted as follows:

1. Establish telephone communication between director and guns.
2. Set switchboard for normal operation; *i. e.,* director to plotting room, which in turn transmits to guns.
3. At the computer or rangekeeper, have time motor off, power switch on.
4. Set *Vs* and *Ds* at their zero values on their respective computer counters.
5. Set and lock level and crosslevel at zero.
6. At the guns, set zero values of *Vs* and *Ds;* put the guns in local, hand, or manual control.
7. Select a distant target off one beam. Train the director until the vertical wire is just off the target, so that motion of the ship will carry the wire across the target.
8. Obtain the range to the target by the most accurate means available, and set the parallax correctors to give the proper correction for this range.
9. Match pointers at the guns.
10. As the director line of sight swings on target, the director trainer calls (phone) "Mark" to the gun trainer. This is continued, the gun trainer meanwhile moving the gun, from one direction, until both gun and director telescopes are on the target at the same instant. The amount of displacement between the follow-the-pointer dials at the gun is the amount of error and should be recorded. This process is repeated, with the gun trainer bringing his vertical wire on target from the opposite direction, and the error recorded. The algebraic difference between the two errors is the *lost motion* of the gun. The mean of the two errors is the *gun error.* For example, if the errors are +2 minutes and −4 minutes, the lost motion is 6 minutes and the gun error is − 1 minute.
11. Repeat the process, using a target on the other beam if practicable, and in any case a target at a widely different train angle from the first, and record the gun error and lost motion.

The gun errors should be equal and small. If they are equal and large (2 or 3 minutes larger than the lost motion), it is an indication that a constant error exists, and that this error may be corrected by adjusting the train response. In so doing, the dial which shows the actual train of the element (not the dial on the synchro receiver) must be moved. If the errors are not equal, a complete train check is necessary.

The complete train check is exactly like the test described above, except that a series of targets is used, at 10° or 15° intervals if possible.

The complete train check will furnish gun errors which, when plotted with their bearings as abscissas, should show a slightly ragged scattering of points. A line parallel to the abscissa which passes through the mean of these points (*i. e.,* with approximately equal deviations above and below the line) can be considered as the zero error line. Its distance above the abscissa will be the constant error of the system, which can be removed by adjusting the response. If a sine curve results, it indicates errors such as improper parallax settings. If the points are erratic with large deviations from the zero line, it indicates damage to the dial drive shaft, such as a sheared coupling or slipping gears.

21D4. System alignment in elevation

Article 21C5 has described how a reference plane is selected. To adjust the battery to this reference plane, it is necessary to compile data on the relative positions of all roller paths concerned. This is done by means of a *horizon check,* which compares the elevation angles on the dials of director and guns when all are pointed at the horizon, at a series of points completely around the horizon.

Steps in performing a horizon check are as follows:

1. Choose a day when the ship has little roll and the horizon is clearly defined.

2. Man stations and phones.

3. Make sure that the synchro transmission system has been checked recently, and that the director has been checked on its bench mark.

4. If possible, use the reference director with no roller-path inclination compensator.

5. Record the roller-path inclination compensator setting on the gun concerned. It should agree with the value determined during the last system alignment check in elevation.

6. Look up the height of gun and director, and compute the dip to the horizon from each. From this information can be computed the *dip correction* for each gun, by subtracting the dip angle for the gun from that for the director.

7. Set the dials of the computer or rangekeeper so that no corrections in elevation are introduced by its mechanism.

8. If the test is to be performed with the boresight telescope, ship the scope. If the gun sights are to be used (the normal procedure), they must have been boresighted recently. Set a positive value of sight angle at the gun and record this setting. The purpose of setting in this sight angle is to ensure that the elevation reading of the gun will be higher than that of the director at all bearings.

9. Train the director to a given bearing; elevate or depress the director line of sight so that it will move across the horizon as the ship rolls. Record for later reference the value of director elevation used on each bearing.

10. Train the gun to the same bearing as the director.

11. The gun pointer depresses his gun until it is approximately on the horizon. When the director sight crosses the horizon, the director pointer calls "Mark", and the gun pointer turns his handwheels until his line of sight crosses the horizon simultaneously. When he is *on*, he checks back to the director exactly on the mark, so that when either one calls "Mark" the other will be exactly on the horizon. To eliminate lost motion, always move the director and gun lines of sight onto the horizon from the same direction.

12. When the gun is *on*, read and record both the mechanical and the follow-the-pointer dials. The follow-the-pointer dials will read the total uncorrected gun error, and this should equal the difference between the director elevation and the gun elevation as read from the mechanical dials.

13. Repeat the foregoing process at 10° or 15° intervals throughout the training arc of the gun.

14. Obtain the uncorrected gun error by subtracting the director elevation from the gun reading (never the reverse), and record the result for each bearing.

A sample of data obtained in the foregoing manner is as follows:

Bearing	*Gun*	*Director*	*Difference (Uncorrected Gun Error)*
0°	1990	1976	14
15°	1991	1979	12
30°	1993	1982	11
45°	1993	1981	12
60°	1991	1978	13
75°	1990	1974	16
90°	1988	1968	20
105°	1987	1963	24
120°	1988	1960	28
135°	1990	1958	32
150°	1988	1951	37
165°	1990	1950	40
180°	1992	1950	42
195°	1990	1946	44
210°	1991	1946	45
225°	1992	1948	44
240°	1991	1948	43
255°	1995	1955	40
270°	1994	1957	37
285°	1995	1963	32
300°	1993	1965	28
315°	1990	1966	24
330°	1987	1968	19
345°	1988	1972	16
360°	1990	1976	14

The foregoing results are most conveniently plotted by the sine-curve method as shown in figure 21D1. After the data have been plotted, find the zero axis of the resulting sine curve. Note that the example shown here is for the full 360° arc of train, which is a condition almost never realized in practice. Hence, while both a high point and a low point are shown on our sample curve, only one of these points may be present on the curves obtained in an actual installation. The method of obtaining the zero axis to be described is applicable if either the high point or the low point of the curve can be located. Simply take a point on the sine curve of a bearing 90° away from the high point or the low point and through it draw a line parallel to the abscissa. This line is the zero axis, and its distance above the abscissa represents the error due to all causes other than roller-path inclination, with respect to the horizontal. Figure 21D1 shows how this error is broken up into component parts. Sight angle and dip correction are known values; the remaining error represents the *system error*. This constant system error can be removed by adjustment of the elevation response at the gun.

The low point of the curve represents the bearing and inclination of the high point of the gun roller path, with respect to the reference plane (in this case, the director roller path). If no low point is shown on the plotted curve, it may easily be calculated, since it would occur at a bearing 180° from the high point of the curve. Further, it would occur at the same distance from the zero axis of the curve as did the high

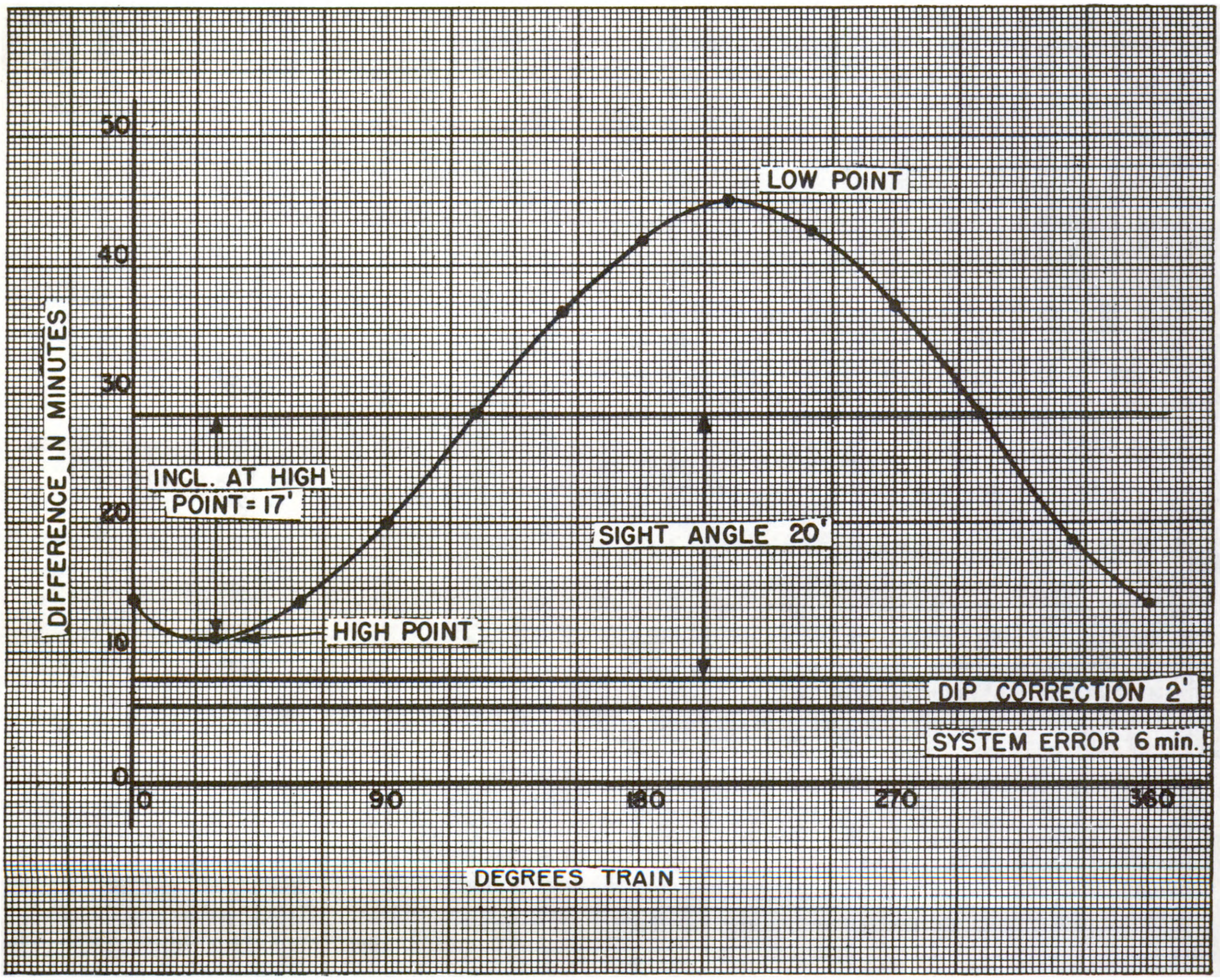


FIGURE 21D1.—Determining system error in elevation, using sine-curve methods.

point. The bearing of the low point of the curve represents the bearing of the high point of the gun roller path. The distance of the low point below the zero axis of the curve represents the inclination of the gun roller path. In the example shown in figure 21D1, the high point of the gun roller path (represented by the low point of the sine curve) is at 30° train, and the inclination at that point is 17 minutes. Thus, for this example, the following desired data are available:

Bearing of high point	30 degrees
Inclination of high point	17 minutes
Constant error of system	6 minutes

At first glance it may be difficult to understand why the low point of the since curve represents the high point of the gun roller path. This may be clarified by the following considerations:

1. In order to keep their lines of sight on the horizon, both director and gun must have a constant elevation (depression) *with respect to the horizontal* on all bearings. As a result, the elevation difference between the director and gun (with respect to the horizontal) must be a constant value.

2. If the elevation difference with respect to the horizontal is constant, then the difference with respect to any other common plane (including the reference plane) must be constant.

3. The gun elevation readings taken in a horizon check are measured with respect to the gun's roller path, not with respect to the reference plane. If the roller path is inclined with respect to the reference plane, such inclination must be added algebraically to the gun elevation reading in order to determine the gun elevation with respect to the reference plane.

4. At any bearing where the inclination of the gun roller path is *above* the reference plane, the gun elevation reading is *less* than the actual gun elevation with respect to the reference plane.

5. Since the director reading is always subtracted

from the gun reading, when the gun reading is *less* than actual gun elevation with respect to the reference plane, the difference will be *smaller*.

6. Since the difference is what is plotted to obtain the curve, the smaller difference results in a lower point on the curve. This corresponds to a *higher* point on the roller path, as shown in *4* above.

21D5. Calculating correct compensator setting

The horizon check is usually made with some setting already on the roller-path tilt compensator. The tilt found by the check, therefore, is not the total inclination but only the uncorrected inclination. It is an additional inclination to that for which the compensator has been set. This newly discovered inclination must be added vectorially to the inclination previously known to exist, in order to determine the total inclination for which the compensator must be set. This may be done graphically, as shown in figure 21D2. In this figure the results obtained previously were used to illustrate the method, which is as follows:

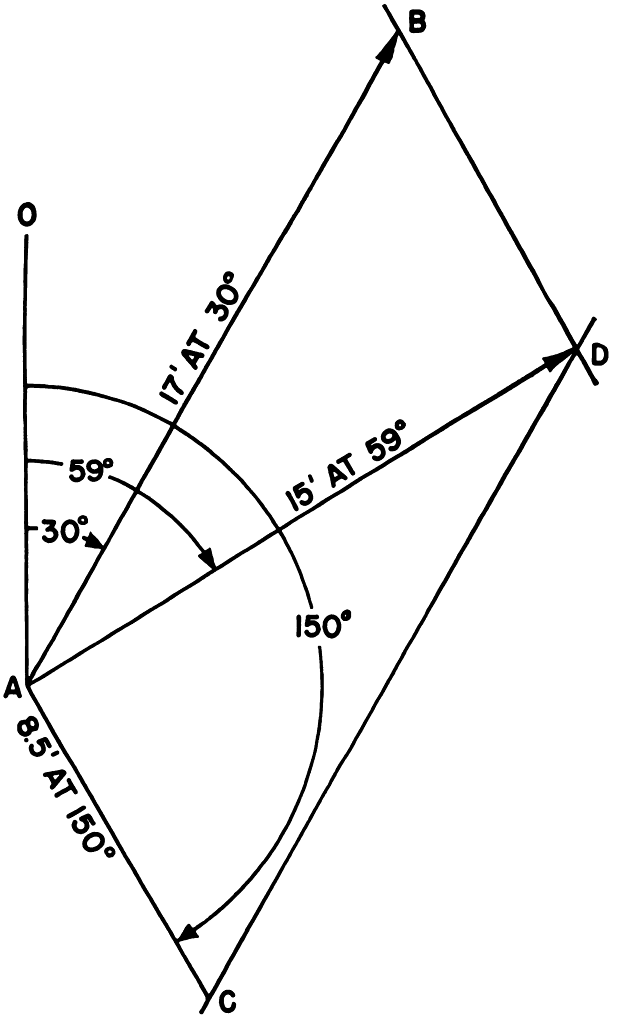


Figure 21D2.—Compensator-setting calculation.

1. The line OA is drawn to represent zero train.
2. The original setting of the compensator (8.5′ at 150°) is plotted as line AC. This is done by measuring off the angle clockwise from OA, and measuring the inclination on that line to a convenient scale.
3. The inclination found (17′) is plotted as AB on bearing 30 degrees.
4. CD is drawn parallel to AB, and BD is drawn parallel to AC. These lines intersect at D.
5. A line AD is drawn from the origin to D. This line represents the total inclination. Its bearing (59°) and length (15′) may be read according to the previously established scale. These are the data that must be set into the compensator.

It should be noted that compensators are constructed to read the error rather than the correction. Thus, if the error is 15′ at 59°, the bearing scale is turned to 59°. Then the inclination of 15′ is set on the inclination scale, and the adjustment is completed.

21D6. Simple elevation check

When at sea, it is desirable to perform a simple elevation check at frequent intervals. The method is the same as that in the horizon check, except that each gun is checked at only one point on the horizon. The difference between gun and director reading after correction for sight angle should equal the dip correction. If it does not, an error of some sort is present and must be investigated. Before undertaking a complete horizon check as a result of such disagreement, however, check to see that the transmission system is functioning properly, and that the roller-path tilt compensator is at its proper setting, both for bearing and for inclination.

21D7. Other checks

After a battery has been aligned in elevation, a test of the automatic follow-up system should be made. This involves training on a target, setting up the problem in the computer and positioning the gun in automatic (using computed gun orders), setting the sights according to generated sight angle and sight deflection, and checking to see whether the gun telescopes are on target. If they are not *on*, the amount that *Vs* and *Ds* must be changed from the computed values to bring the sights on the target represents the error of the system. To eliminate trunnion tilt errors when this test is made, it should be done when there is little or no roll.

The necessity for alignment of the fire control radar beam with the director optics should be mentioned. It is obvious that the radar line of sight must be parallel to the optical line of sight; otherwise false values of target position would be measured when tracking by radar. This alignment, the mechanical details of which vary with different types of radars and directors, is comparatively simple. Basically, it consists of placing the director exactly on the target optically and adjusting the position of the antenna until the pointer's and trainer's radar scopes give the optimum "On target" indication. When this condition has been satisfied, the antenna is locked in place.

The preceding discussion of battery alignment has dealt only with gun batteries. Proper alignment is equally important in any other director-controlled battery such as torpedo, rocket launcher, *etc.;* but the methods used will vary with the characteristics of the battery to be aligned.

E. Firing Stop Mechanisms

21E1. General

Theoretically the battery is aligned when, with the dials matched and parallax on zero, all the lines of sight and the axes of all gun bores are parallel, regardless of the ordered angles of gun train and gun elevation. In practice, however, the battery check is not complete until: (1) the firing cutout cams in each gun have been plotted, cut, and installed; and (2) the firing stop mechanisms have been checked, with the cams installed, to ensure that both the mechanical and the electrical firing circuits are interrupted properly whenever the guns move from a zone of safe fire to a danger zone.

The importance of this phase of the procedure cannot be overemphasized. The numerous casualties that have occurred because a ship has fired one of her guns into her own superstructure testify to the seriousness of any misalignment of the firing stop mechanisms. It is equally important to note that in all cases these casualties could have been prevented. They resulted from negligence on the part of the ship's personnel: the cams were cut improperly and in some cases misaligned, or the firing stop mechanisms were inoperative through lack of preventive maintenance.

Firing stop mechanisms are designed to interrupt the mechanical and electrical firing circuits whenever the guns are trained or elevated to a position where firing the guns would endanger ship's personnel or damage own ship. They should not be confused with the frameworks of steel tubing or depression-stop cams that are used occasionally to limit the movement of light machine guns to safe zones of fire. Firing stop mechanisms do not interfere with the free movement of the gun; this is done by the train and elevation limit stops.

The Bureau of Ordnance has issued definite instructions for the guidance of the personnel responsible for plotting, cutting, installing, and checking firing cutout cams and mechanisms. In all cases these regulations must be adhered to strictly. In addition, special instructions govern particular gun installations; for example, the firing limits of 40-mm gun mounts.

21E2. BuOrd regulations for firing cutout cams

In accordance with Bureau of Ordnance instructions a firing stop cam installed on any gun shall be so designed that it will prevent firing into fixed structure and into certain other areas under the following conditions:

1. When removable parts of the ship's structure such as stanchions, handrails, life lines, davits, and equipment such as boats, chests, lockers, and hatches have been removed or stowed so as not to obstruct the line of fire.
2. When, for the firing bearing (azimuth and elevation) under consideration, movable parts such as guns, turrets, cranes, and booms cannot be so disposed of as to clear the line of fire.
3. When, for the firing bearing (azimuth and elevation) under consideration, the personnel cannot be so disposed as to clear the line of fire.

Gun firing cutout cams designed in accordance with the above instructions *will not* restrict the firing of the guns so as to prevent damage to the following:

1. Personnel within the danger blast area of the gun.
2. Material that can be, but has not been, moved clear of the line of fire.

In order that firing stop cams may be designed for the maximum possible zone, the Bureau of Ordnance does not approve of cutting firing stop cams to provide protection of forestays, halyards, antennae, and such top hamper. Peacetime target practice must be arranged so as to keep the fire clear of these obstructions. In wartime these hazards must be accepted.

For guns of 5-inch and larger caliber a minimum clearance of one caliber shall be maintained between the extension of the axis of the gun bore and the fixed structure. For protection of other installations, this minimum clearance is computed with the other guns and directors at zero-degree elevation and the angle of train at which they are normally secured. For 3″/50 caliber guns a minimum clearance of 5 inches is required, while for 40-mm guns a minimum clearance

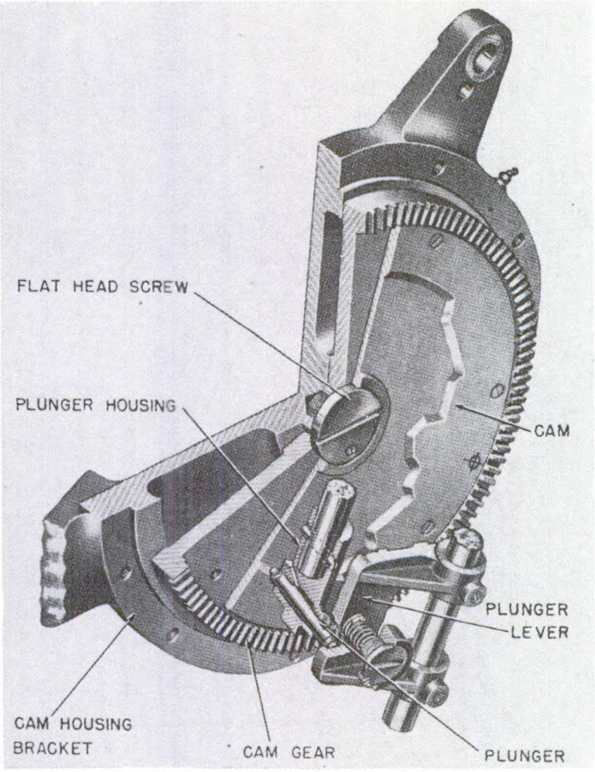


FIGURE 21E1.—Firing stop mechanism plunger and cam.

of 8° must be maintained. This seemingly large clearance for 40-mm guns is due to the lag between the time the cutout mechanism functions and the time that the guns actually cease firing.

For 20-mm guns the safe zone of fire must be plotted with the ready-service lockers open. This is necessary because in time of battle these lockers are normally open, or may be open, so that the ammunition can be reached easily.

21E3. Turret firing cutout mechanisms

The majority of the main-battery guns of 6-inch bore and larger have separate firing cutout mechanisms for train and for elevation. In train the cam surface is fastened to the stand near the roller path, while the plunger and cutout switch are located on and move with the carriage. Cutout action is obtained by securing cam surfaces to the stand at those relative bearings coincident with the danger zones of fire. The elevation cutout is a flat cam-and-plunger mechanism mounted on the deck lug of the gun. Movement of the gun in elevation, through a mechanical connection, rotates the cam.

On these large-caliber guns only the electrical firing circuit is interrupted by the cutout cams. The percussion firing circuit is not cut out by the cams; however, warning lights are energized in the mount or turret to indicate that the gun is in a danger zone and should not be fired by percussion.

The proper settings for these firing cutout mechanisms are outlined in the applicable OP's. Usually the OP's will list the settings for the individual turrets in ships of a class. After the cams are installed, they must be checked by the methods similar to those outlined for smaller guns.

21E4. Profile-cam mechanisms

Dual-purpose guns, and nonturret guns generally, incorporate mechanisms wherein one cam, referred to as a profile cam, controls the firing circuit when the gun is in or near a danger zone of fire in either train or elevation. This type is used on 40-mm, 30″/50, 5″/38, 5″/54, and some larger-caliber guns. The mechanical action of these mechanisms differs slightly from gun to gun, but in principle they are the same and can be considered collectively.

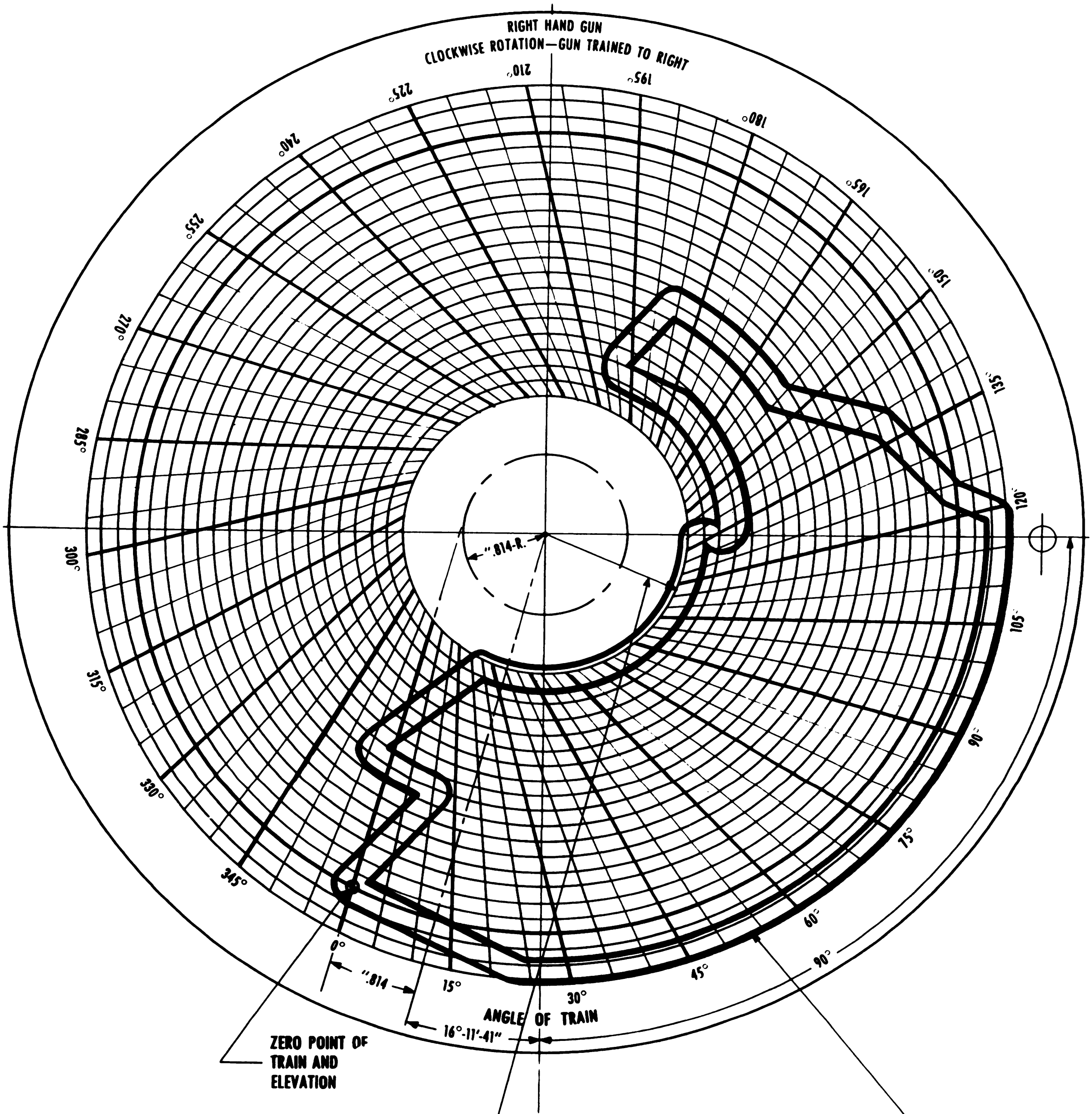
The cutout feature of profile-cam firing stop mechanism is accomplished by the action of a plunger or cam pin on a lever and a circular profile cam. When the plunger rides up on a high point of the cam, which represents a danger or nonfiring zone, it pushes against the plunger lever, which in turn causes sufficient movement of another lever or levers to interpose a break in the firing circuit. In the 5″/38 dual-purpose gun, this movement interrupts both the electrical and the percussion firing circuits.

Figure 21E1 shows a cut-away view of a typical firing stop mechanism plunger and profile cam; this one is from a 5″/54 mount. The cam is turned by gun train order at one-to-one speed, while the plunger mechanism moves radially from near the center to the edge of the cam in accordance with gun elevation order. A point near the center of the cam represents maximum gun elevation, and the outer edge minimum gun elevation.

The rise from the cut-away to the raised portion of the cam is inclined to the face of the cam by an angle of 30 degrees. This permits the plunger to ride from the low machined-out surface of the completed cam to the high surface without excessive wear or scoring. Cutout occurs when the plunger is two-thirds of the way up the incline. This must be borne in mind when laying out the cam. It is necessary to scribe two additional lines, besides the line representing the danger zone of fire, on the cam. These lines represent the top and bottom of the incline.

21E5. Plotting the cams

The entire firing stop mechanism, with the exception of the profile cam, is assembled and installed on



85° ELEVATION =1".434-RAD.
80° " =1".567- "
75° " =1".704- "
70° " =1".845- "
65° " =1".988- "
60° " =2".133- "
55° " =2".280- "
50° " =2".428- "
45° " =2".578- "
40° " =2".729- "
35° " =2".880- "

30° ELEVATION =3".032-RAD.
25° " =3".185- "
20° " =3".338- "
15° " =3".491- "
10° " =3".645- "
5° " =3".800- "
0° " =3".954- "
5° DEPRESSION=4".109- "
10° " =4".264- "
15° " =4".420- "

Figure 21E2.—Sample cam-plotting sheet for a 5"/38 twin mount.

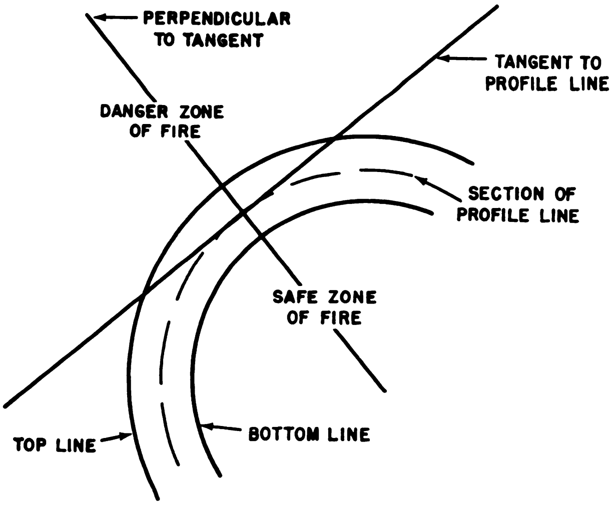


FIGURE 21E3.—Plotting the top and bottom lines.

the mount during manufacture. As the profile of the cam will vary with the location of the gun, the cam must be plotted after the gun is installed aboard ship. The precise method of plotting the cam depends upon the type of gun. One of the methods which can be used for a 5"/38 gun will sufficiently illustrate the principles of the operation.

This method consists of mapping out the zone of permissible fire by means of a boresight in the bore of the gun, plotting the minimum safe angles of elevation at successive angles of train on a cam-plotting sheet, and transferring the plot to the cam blank. Cam-plotting sheets, such as illustrated in figure 21E2, are available at all naval shipyards. It is important to note that plotting sheets are made for each specific caliber, mark, and modification of gun, and that right and left guns of a twin mount use different sheets (one cam turns clockwise, the other counterclockwise). Before transferring the plot to the smooth copy of a plotting sheet, it is in each case necessary to consult the OP or OD for the particular type of mount. This will contain such information as the minimum radius of all curves in the plot, the radial distances of the top and bottom of the cam slope from the actual cutout line (see fig. 21E3), and other data essential to accurate plotting.

It should be noted that, in tracing the safe-fire zone of any mount with more than one gun, a separate cam must be plotted for each gun (each pair of barrels in the case of the 40-mm only). Thus one gun may stop firing upon training toward the edge of an obstruction while the other gun or guns will continue to fire until the mount has been trained a few degrees more toward the ship's structure.

21E6. Final steps

After a cam has been plotted by any one of the methods listed, it is turned over to the yard for machining. When the machine work is completed and the cam is returned to the ship, it must be installed and synchronized according to the instructions contained in the ordnance publication pertaining to that type of gun.

Finally the accuracy of the cam profiles and the adjustment of the firing stop mechanism must be checked. The following is a suggested procedure; however, the voltmeter recommended can be replaced by an electric lamp of the correct voltage rating, if desirable.

1. Make sure that the gun is *not loaded.*
2. Lay the gun so that it is *outside* of a danger zone.
3. Complete the firing circuit as for local firing.
4. Connect a suitable standard voltmeter between the firing pin and ground, or across the terminal of the firing-cutout switch.
5. Firing-circuit voltage should be indicated by the voltmeter, thus establishing continuity of the circuit.
6. Lay the gun so that it is *within* a danger zone. The voltmeter should now read zero.
7. Train and elevate the gun in and out of the firing zone, at various points, verifying that the operation of the firing stop switch, as indicated by the voltmeter, takes place at the proper points.
8. If percussion firing is also included in the cutout mechanism, check to see that percussion firing cuts out at the same points as those at which the switch in the firing circuit opens.

If a voltage is present in step No. 6 or during those parts of step No. 7 when the gun is in a danger zone, a defective firing stop switch, a defective or short-circuited plug, or faulty cable insulation is to be suspected, and immediate steps must be taken to locate and correct the defect.

The preceding section on firing cutout cams has briefly presented the theory of these mechanisms, but when it comes to plotting and cutting the cams, remember this: always consult the OP; there is no substitute for exact knowledge.

Chapter 22

NAVAL GUNFIRE SUPPORT

A. General

22A1. Historical introduction

In the course of World War II, naval task forces frequently carried out bombardments of enemy installations on shore. After the ineffective results noted during the Tarawa operation in November 1943, shore bombardment techniques were gradually improved and refined through successive landings at Roi-Namur, Eniwetok, Saipan, Guam, Peleliu, the Philippines, Iwo Jima, and Okinawa. Later, the Korean conflict gave frequent opportunity for the application of the techniques learned in World War II; in particular, the use of naval gunfire to support the landing of troops on defended enemy territory.

Opposed amphibious landing is one of the most hazardous types of military operation. Until World War II, many military authorities believed that such an operation was too hazardous to be attempted. This belief was based largely on the British experience at Gallipoli, in World War I. This operation failed, largely because of the absence of organic supporting arms prior to, during, and immediately after the landing. The value of naval gunfire support rests principally on its continuous availability during these critical periods.

The mission of naval gunfire in support of landing operations is to aid the seizure of the objective by reducing or neutralizing shore installations and troops that oppose our forces prior to and during the landing, and by assisting the advance of our troops after the landing has been made. This support is vitally important in the period after the troops have landed but before adequate artillery can be brought into action. To be successful, naval gunfire support for amphibious operations must be carefully planned in advance, and must be executed with skill and dispatch. Full exploitation of support can be achieved only if ground, naval, and air personnel understand the organization, basic techniques, capabilities, and limitations of naval gunfire support, and follow the standard procedure which has been agreed upon by the joint services.

22A2. Mission of naval gunfire support

Naval gunfire is delivered from ships' batteries not only in support of troop operations, but of related naval and air operations, such as mine warfare activities, air-sea rescue operations, reconnaissance and demolition operations, demonstrations, feints, raids, flak suppression during air strikes, and interdiction of coastal roads, railroads, airfields, and troop assembly areas. All these activities rest on the same basic principles as the naval gunfire support of amphibious operations.

The basic task of naval gunfire support units in an amphibious operation is to support the seizure of the objective by destroying or neutralizing:

1. Shore installations that oppose the approach of ships and aircraft to the objective.
2. Defenses that may oppose the landing.
3. Defenses that may oppose the post-landing advance of the troops.

These tasks are carried out in the preparation of the objective for the landing, the support of the landing, and in post-landing support.

22A3. Advantages of naval gunfire for troop support

Naval gunfire has many capabilities for troop support in landings which are not possessed by artillery. The principal ones are:

1. *Availability.* Gunfire support ships are continuously available before, during, and after the landing, as long as the zone of action ashore is within the range of the ships' guns.

2. *Mobility.* Within the limitations of navigation, ships can move rapidly from one area to another as the situation ashore develops. At the same time, the most favorable ranges and lines of fire can be fully exploited, and enemy counterfire can be evaded.

3. *High rate of fire.* Power loading and mechanical ammunition supply makes it possible to deliver a large volume of fire in a short time. This characteristic is of great value in neutralization missions.

4. *High muzzle velocity and flat trajectory.* Naval guns, particularly those of heavy caliber, have great penetration and destructive power, especially against installations presenting vertical surfaces.

5. *Small deflection pattern.* The comparatively small dispersion in deflection of naval guns makes them valuable for close support of troops when the line of fire can be made parallel to the troops' front line (enfilade fire).

6. *Variety of weapons and types of ammunition.* Calibers of guns range from 20-mm to 16-inch, with ammunition of many types, including armor-piercing, fragmentation, and reduced-charge. Other available weapons include rocket and guided missile launchers, with a wide variety of ammunition types for each.

22A4. Limitations of naval gunfire for troop support

The tactical employment of naval gunfire in support of troops has certain limitations, which must be taken into consideration in both planning and operational stages. The most important limitations are:

1. *Necessity for observation.* Naval gunfire, except for area fire on very large targets, must be observed and corrected to be effective. This requires a spotting agency, such as a ground spotter, air spotter, or shipboard spotter.

2. *Navigational limitations.* Ships are forced to remain in safe, navigable, mine-free waters, and therefore sometimes cannot take advantage of the positions most favorable for the attack of targets. In some cases, ships cannot fire at all on certain defiladed (located on a reverse slope) targets. Obviously, the maximum range inland is limited by the position of the ships, as well as by the characteristics of the weapons used. Further, the fact that the ship is in motion requires the continuous and accurate fixing of the ship's position for delivery of fire on targets not visible from the ship.

3. *Communications limitations.* Radio and visual communications between ship and shore are not as flexible, reliable, or secure as communications by wire or telephone.

4. *Limitations of pattern.* By comparison with artillery, naval guns have a small deflection pattern, a large range pattern, and a flat trajectory. This is an advantage in some respects, but requires careful selection of lines of fire when engaging targets near our own troops. The difficulty of fire against defiladed targets may be overcome by using reduced-velocity charges or by increasing the range, to obtain a greater angle of fall.

5. *Limited ammunition capacity.* The limited capacity of the ship's magazines, coupled with the fact that a ship must always retain a certain amount of ammunition for its own protection, restricts the ability of any one ship to maintain uninterrupted support over an extended period of time. This disadvantage may be overcome by providing adequate ammunition replenishment and by rotating ships assigned to support missions.

22A5. Terminology

Naval gunfire may be classified in various ways, as shown in the following paragraphs. The classifications in use are interrelated, making it necessary to employ terms from several types of classification for a full description. These classifications are made with respect to:

1. Effect sought:

   a. *Destruction.* Deliberate and accurate fire, usually delivered at short range, for the purpose of destroying a target, usually a material object.

   b. *Neutralization.* Rapid, fairly accurate fire delivered for the purpose of hampering, interrupting, or preventing enemy fire, movement, or action. The destruction of weapons and personnel is a secondary consideration. The effect of neutralization is comparatively temporary, and such fire may have to be repeated.

   c. *Maximum damage.* Fire against a target which is desired to be destroyed, but which probably cannot be completely destroyed without excessive ammunition expenditure, because of its size, location, range, or lack of vulnerability to naval gunfire.

2. Tactical use:

   a. *Close supporting fire.* Gunfire delivered on enemy targets which, because of their proximity, present an immediate and serious threat to the supported unit.

   b. *Deep supporting fire.* Gunfire delivered on objectives not in the immediate vicinity of friendly forces, for the purpose of neutralizing or destroying enemy reserves and weapons and interfering with enemy command, supply, communications, and observation.

   c. *Harassing fire.* Sporadic fire delivered during otherwise quiet periods to prevent enemy rest, recuperation, or movement, and in general to lower enemy morale and combat efficiency.

   d. *Interdiction fire.* Fire designed to prevent or curtail the use by the enemy of an area, bridge, defile, airfield, route of communication, or the like.

   e. *Illuminating fire.* Gunfire employing star shells to illuminate the enemy, to detect his movements, to aid our own observation, or to facilitate own troop movements.

   f. *Preparation fire.* A heavy volume of prearranged neutralization fire, delivered just prior to a landing or a ground attack by friendly forces on enemy positions.

g. *Counterbattery fire.* Gunfire delivered against active enemy guns and fire control stations for the purpose of silencing the guns.

h. *Screening fire.* Gunfire employing smoke projectiles, delivered to obscure the enemy's vision of friendly units and their deployment, movement, or maneuvers.

3. Degree of prearrangement:

a. *Prearranged or scheduled fire.* Gunfire that is formally planned and executed against targets of known location. Such fire is usually planned well in advance and is executed at a predetermined time or during a predetermined period of time.

b. *Call fire.* Gunfire delivered at the request of troop units ashore, or of some spotting agency. Call-fire missions must not be interrupted without permission of the unit requesting the fire, except in case of emergency.

c. *Opportunity fire.* Gunfire delivered without formal planning or troop request on newly discovered targets, or upon targets of a transitory nature. Targets of opportunity may present themselves to the firing ship at any time, but fire must not be delivered without due regard for the safety of friendly troops. Ships delivering fire on targets of opportunity in close proximity to own troops require the approval of the troop echelon concerned before opening fire. Ships executing deep support missions must assure themselves that the target of opportunity is within their assigned sector of responsibility.

4. Technique of delivery:

a. *Direct fire.* Gunfire delivered on a target by using the target itself as a point of aim for laying the guns or director.

b. *Indirect fire.* Gunfire delivered on a target which is not itself used as a point of aim for laying the guns or director. Direct fire is usually used on targets which can be seen (by optics or radar) from the firing ship; indirect fire is always used on targets not visible from the ship.

5. Type of fire:

a. *Area fire.* Gunfire delivered in a prescribed area. Area fire is generally neutralization fire.

b. *Point fire.* Gunfire directed at a definite material target in order to destroy that particular object.

c. Defilade fire (reverse-slope fire). Gunfire delivered on targets located behind some terrain feature, such as a hill or ridge, which masks the target.

d. *Enfilade fire.* Gunfire delivered on a target in such a manner that the range pattern of the fall of shot coincides with the long axis of the target.

Some other general terms used in naval gunfire support operations are:

1. *Amphibious Task Force* (*ATF*). A task organization under naval command composed of assault shipping, embarked troops, and supporting naval units and tactical air units.

2. *Amphibious Troops* (*AT*). The troop elements assigned to an Amphibious Task Force.

3. *Advance Force.* A task organization of ships which conducts operations such as reconnaissance, minesweeping, underwater demolition, diversionary raids, and preliminary bombardment prior to the arrival of the main body of the ATF in the objective area.

4. *Attack Force.* A subdivision of an ATF consisting of assault shipping with embarked troops and supporting naval and tactical air units, operating to establish a landing force on shore and support its operations thereafter. In an operation involving only one Attack Force, it is also the Amphibious Task Force.

5. *Fire Support Group.* A group of ships, part of the Attack Force, assigned the mission of naval gunfire support of an amphibious operation.

6. *Objective Area.* A defined geographical area within which is located the objective to be captured or reached by the military forces.

7. *Objective.* A physical area or location on the ground, usually a readily identifiable terrain feature, which a troop unit is assigned to capture or occupy. Objectives may be designated as intermediate or final objectives.

8. *D-Day.* The day on which an amphibious landing takes place.

9. *H-Hour.* The actual time to the minute at which the leading wave of the landing force touches down on the beach; if the *actual* H-hour differs from the *scheduled* H-hour, the actual time of H-hour is broadcast to all ships and troop units by the Amphibious Task Force Commander.

10. *Zone of Responsibility.* The land in the objective area is divided into zones which are assigned to fire-support units or to individual ships which are responsible for observing, destroying, or neutralizing known enemy installations and for attacking targets of opportunity therein. A ship may fire in its own ZR *without* clearance from any troop unit. These zones include all land area in the vicinity of the landing forces except the Close Support Area.

11. *Close Support Area.* The area between friendly front lines and the near limits of Zones of Responsibility. Support ships may fire into these areas only upon call from supported troop units, *or* after receiving clearance from the troop unit concerned to fire on a specific target.

12. *Preliminary Bombardment.* Bombardment in the objective area delivered by an Advance Force prior to arrival of the main body of the ATF, with the primary purpose of destroying enemy defenses which might hinder or abort the landing.

B. Naval Gunfire Support Operations

22B1. Selection of the weapon

Selection of the gun or weapon to be used in naval gunfire support is determined by the nature and size of the target to be engaged and by the proximity of friendly troops to the target. The 5-inch gun is normally used for close supporting fire; its rapid rate of fire and relatively small pattern size make it an excellent weapon for neutralization and destruction of targets immediately in front of advancing troops. Destroyers are usually assigned close supporting-fire duties because their maneuverability permits them to shift positions easily and quickly and to take positions close inshore for direct fire on targets in coastal areas.

Guns of 8-inch and larger caliber, with their great accuracy at long range, are normally reserved for deep supporting fire. The lethal bursting radii of projectiles from these guns limit their employment in close support. Moreover, ships mounting these guns (battleships and cruisers) are hampered in responding quickly to fire commands because they are less maneuverable than destroyers and their fire control organization is more complex. The larger ships also have to carry out a number of additional duties. The destructive power of the projectiles of large-caliber guns makes them particularly effective against heavy installations ashore.

The 6-inch gun has qualities suitable for either close or deep support, but the light cruisers mounting these guns are better adapted for deep support use, since their maneuverability is restricted.

The 3-inch and 5-inch guns of DE's, APD's, DM's, and DMS's are suitable for harassing fire missions of the sort often executed against areas remote from our own troops, such as towns, harbors, and coastal air strips. The use of these ships for this purpose provide a necessary feature of support and releases ships with more accurate fire control equipment for use where precision fire is required.

40-mm guns are effective for area neutralization where heavier caliber guns are not required. The fire control installation used with these guns is inadequate for indirect fire or safe close supporting fire. These guns are particularly effective against shoreline targets, especially enemy personnel in caves. When such fire is controlled by the dual-purpose gun directors, it is accurate and effective at short ranges; when not so controlled, larger safety limits with respect to proximity of own troops must be allowed.

22B2. Specialized fire-support ships

The support of troops in landing operations has brought forth many new special weapons and specialized fire-support craft. The most important among these are:

1. *The LSMR.* This is primarily a rocket ship; its main armament consists of launchers for 5-inch spin-stabilized rockets, the maximum range of which is about 11,000 yards. This craft can be used for deep support, harassing, and neutralization fire as well as for beach neutralization. Because it is equipped with a rocket fire control installation, it can use its fire somewhat closer to own troops than the rocket LCS, which lacks this advantage.
2. *Inshore fire-support ship* (*IFS*). The inshore fire-support ship, a recent addition to the fleet, is designed for providing close support to troops in amphibious landings. The major armament consists of rapid-fire rocket launchers. A crew of 162 will man this 245-foot vessel, whose twin screws are powered by diesel engines. The displacement of the ship is 1,500 tons.

22B3. Projectiles and fuzes

The selection of the projectile type to be used in support of troops depends upon the type of target and the effect sought on that target. High-capacity (HC) projectiles are designed especially for use in shore bombardment. They have a great explosive content at the expense of penetrative ability and produce a heavy blasting and shrapnel effect. HC is therefore suitable for neutralization or for destruction of relatively light installations. Antiaircraft common (AAC) projectiles are similar to HC projectiles in explosive and penetrative qualities. Their effective bursting radius of 35 to 50 yards makes them most satisfactory for close-support neutralization fire. Armor-piercing (AP) and common (COM) projectiles are designed to penetrate armor plate before detonating. Their use in shore bombardment is limited to fire on fixed enemy defenses such as concrete pillboxes and blockhouses which cannot be reduced by HC projectiles. White-phosphorus (WP) projectiles have been found very useful for screening, incendiary, and antipersonnel effect. They may also be used as "identifying or marker shot" to identify salvos, to permit spotting when the impact burst is invisible due to foliage, or to give a prearranged signal to the troops supported. Illuminating (Illum) projectiles are used to provide illumination only.

The type of fuzes used with HC, AAC, and WP projectiles may be varied to meet different objectives. Mechanical time fuzes may be used to provide air bursts for maximum effect against personnel and light equipment. They should be set to burst 25 to 50 feet directly above the target. Proximity fuzes accomplish the same purpose with greater accuracy and less difficult fire control, as they compensate automatically for variations in ground elevation. Point-detonating fuzes, like proximity fuzes, require no advance setting but produce a lower and more concentrated burst, often desirable for demolishing equipment. Base-detonating fuzes are, of course, required whenever armored or other heavy structures must be penetrated.

22B4. Phases of support

It is convenient to divide the support for a landing operation into three general phases as follows:

1. *Prelanding bombardment.* This phase, which may commence well in advance of D-day, utilizes quick raids by surface ships to inflict damage and cause confusion, after which the ships retire. Similar strikes may be carried out by aircraft during this phase.

More often the bombardment group will move into position a few days prior to D-day and commence its schedule of prearranged fire which may continue right up to H-hour (the time of landing of the first wave of troops) or may be interrupted by retirement of the bombardment group for reasons of safety.

During this period, the effect sought by the bombardment is destruction of beach defenses, gun control and observation posts, or any defenses which could effectively oppose the landing. Slow, deliberate, close-range destructive fire is used whenever it is possible. In this, as well as in later phases, an attempt is often made to conceal the actual landing beaches by a schedule of fire covering other areas. The number of ships engaged in the prelanding bombardment, its duration, and the type of ammunition expended will depend upon such factors as the number of ships and planes available, the logistics (especially ammunition supply), and the nature of the terrain and its defenses.

In addition to its primary purpose of destroying designated targets which may hamper the landing, the force is often called upon to provide cover for minesweepers, underwater demolition teams, and hydrographic survey vessels. During the night it may engage in harassing fire to break down enemy morale. During the last hours prior to H-hour it may be called upon to provide interdiction fire to prevent assembly of reinforcements and their movements into the area of the landing beaches to man installations or repair damaged equipment. On D-day, prior to embarkation of troops, the bombardment of strong resistance points will be intensified. The force may be called upon to cover the final minesweeping operations and the approach of the attack force, especially the transports. When the transports are in position and the landing beaches are disclosed to the enemy, fire can be concentrated on strong points which intelligence reports or observation indicate have not been destroyed.

During this period, also, air strikes are often scheduled to bomb and strafe the beaches. Provisions must be made to control fire so as to avoid hitting friendly planes.

2. *Support during the landing.* The primary missions of naval gunfire in this phase are to protect the transports while the landing force is embarking in boats, to silence batteries which might destroy the assault waves as the boats move in to the beach, and to cover the actual landing of troops. The barrage must be lifted inland or shifted to the flanks as the troops near the beach to avoid hitting the landing force as well as to neutralize strong points from which destructive crossfire could be poured on the beaches. In addition to close supporting neutralization fire on the landing and adjacent areas, deep supporting fire must be concurrently delivered to prevent enemy troop movement toward the landing area and to neutralize more remote opposing enemy defenses.

During the last few minutes, as the first wave nears the beach, a final air strike often parallels the beach, strafing and driving the enemy to cover. Also just before the landing, the rocket and mortar ships close inshore will deliver a devastating barrage, saturating the whole beach area.

The rapidity of events and general lack of information from troops being supported during and immediately following a landing require that most of the supporting fire be planned in advance, for delivery according to a carefully formulated and coordinated time schedule.

It is essential that close and deep supporting fire be scheduled to continue after the landing, in order to neutralize enemy opposition which would hinder the rapid establishment of organized troop units ashore. The postlanding schedule of fire must be carefully planned for coordination with the estimated troop advance ashore, but must be capable of quick modification to permit repeating, extending, or discontinuing any portion of the schedule when the advance differs from that expected. The duration of the scheduled fire after H-hour must extend well beyond the estimated time required to establish effective naval gunfire control agencies ashore.

In the case of heavily defended objectives, scheduled fire for close support must continue at least an hour after the landing, and for deep support at least 4 hours.

3. *Support for troop advance ashore.* Naval gunfire is employed after the landing phase to assist the advance of troops to their final objectives. Close supporting fire from ships assigned to them, daily or upon special request, is made continuously available to troop units in assault. Deep support, including daily destructive fire missions, preparation fire for troop attacks, and night harassing fire, are scheduled for

daily execution in fulfillment of troop requests. This phase of naval gunfire support commences upon the completion of the prearranged scheduled fire in support of the landing and continues until naval gunfire is no longer required for support.

22B5. Land-target problem

Naval gunfire against targets on land offers essentially the same problem as firing at a ship dead in the water, except for the following additional considerations:

1. *Ship's position.* As mentioned before, the geographical position of the firing ship must be continuously and accurately fixed, as from this are determined the range and bearing of the target in many instances when indirect fire must be used.

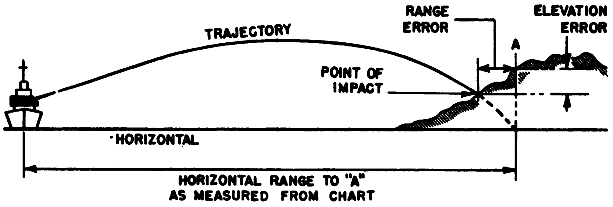


FIGURE 22B1.—Errors resulting from failure to compensate for target elevation.

2. *Terrain.* Terrain features make correction of the fall of shot a difficult problem. Since range tables and rangekeeper solutions in main-battery systems assume the point of fall to be in the horizontal plane, the elevation of the target above sea level must be compensated for in the fire control solution. Figure 22B1 illustrates the errors resulting when the range of a land target is taken from a chart and the target's elevation is not considered. When dual-purpose guns are used for shore bombardment, the antiaircraft fire control systems provide a ready solution to this problem. Terrain features also affect the size of the pattern in range; a forward slope decreases it, and a reverse slope increases it. Figure 22B2 illustrates these effects.

3. *Current effects.* The set and drift of the current will affect the solution of the fire control problem. When determined, drift may be entered into the rangekeeper or computer as target speed; the direction of the set is reversed and introduced as target course.

4. *Parallax.* In order to cover area targets more effectively with the shots of individual salvos, it may be desirable to increase the deflection pattern by setting the horizontal parallax correctors at infinity (i. e., removing horizontal parallax correction from the gun battery).

5. *Varying ammunition.* Frequent and rapid changes in the targets to be engaged require ready accessibility of various types of ammunition and fuzes.

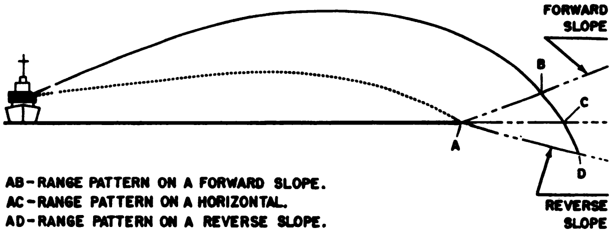

FORWARD SLOPE
B
C
A
D
REVERSE SLOPE
AB-RANGE PATTERN ON A FORWARD SLOPE.
AC-RANGE PATTERN ON A HORIZONTAL.
AD-RANGE PATTERN ON A REVERSE SLOPE.

FIGURE 22B2.—Effect of terrain slope on the range pattern produced by ship's guns.

6. *Principles of employment.* Effective support of troops by naval gunfire is dependent on certain principles of employment and techniques of delivery of that gunfire which might be called tricks of the trade. The following paragraphs briefly discuss these. Prerequisites of effective support are the proper alignment of the fire control system and gun battery, rapid and reliable internal and external communications, and well-trained ship control, fire control, and gun control personnel.

The primary duty of naval gunfire in all phases of the support is the immediate and effective silencing of heavy enemy weapons which open fire on our forces. It is essential that a counterbattery plan satisfying all contingencies be kept in constant readiness and that fire-support ships be ready and alert at all times for the delivery of this fire. When the source of enemy fire is not known, heavy counterbattery fire on suspected sources is delivered pending the determination of the exact location of the enemy battery. The whereabouts of friendly forces must be kept in mind during such an attack.

Only by thorough familiarity with the land areas assigned, achieved through repeated firing, observation, and analysis, can the most effective fire be delivered by ships. The shifting of ships to different areas of responsibility, or frequent shifting of fire between targets widely separated in the same general target area, is avoided.

Unlike surface or air actions at sea, naval gunfire support requires moderately low speeds. The use of high speed in a firing ship requires it to make frequent course reversals in order to remain in its assigned sector, results in unacceptable inaccuracies in establishing the ship's position for indirect fire, takes the ship too quickly beyond effective firing positions limited by terrain features, and may result in prohibitive interference with other activities offshore. A low speed is usually selected which will allow good control of the ship and the supporting fire, consistent with the tactical situation and the submarine menace. If necessary, the ship will lie to or anchor, maintaining desired heading by the use of the engines. Best results for indirect fire will be obtained if ships steam on a steady course at a constant low speed.

Direct fire is employed whenever possible, although indirect methods must always be employed when visible points of aim are not available. Indirect fire requires more ammunition and time than direct fire for equally destructive success. It requires air or ground observation of the fall of shot in order to ensure hits on point targets. The effectiveness of naval gunfire is increased by the employment of an air spotter working with a ground spotter.

Once established, the maintenance of the hitting gun range and deflection is essential to effective destructive fire. Periods of continuous slow fire with reduced salvos are therefore preferable to more rapid fire interspersed with relatively long nonfiring intervals.

The decisive destruction of heavy defenses is greatly enhanced by very close-range, slow, deliberate, direct fire against such installations. Fire-support ships usually operate as close inshore as safe navigation, the tactical situation, enemy shore batteries, and the type of fire required will permit.

Close supporting neutralization fire on the landing area in support of troops about to land, although scheduled to be shifted therefrom on a time basis relative to the estimated time of H-hour, must be adjusted according to the actual position of the troop landing craft. From reports of landing-craft progress received, but primarily from own observation when possible, fire-support ships individually determine when their fire is about to endanger troops nearing shore, and accordingly shift the fire from the landing area.

Close cooperation between ships and the troop units to which assigned for support is essential for maximum effectiveness. Interchange of information between supporting ships and troop units results in more intelligent and effective fire support. Of particular importance in this connection is the safety requirement that all fire-support ships maintain an up-to-date plot of own troop front-line positions as periodically announced by elements of the landing force. This not only prevents endangering own troops, but permits selection of the most suitable line of fire with respect to troop lines. Another consideration is the necessity for safeguarding friendly aircraft operating in the area.

Illumination of land areas by naval star shells is effective in preventing enemy counterattacks, infiltration, and the movement of enemy troops at night. Its morale-boosting effect on our own troops generally results in requests for exorbitant star-shell expenditures to produce unnecessary illumination of the land area throughout the night. Except during actual enemy counterattacks, star shells fired at a reduced rate and at irregular intervals normally discourage enemy movement. Maximum benefit from the limited supply of star shells available requires judicious control and coordination by troop units to avoid silhouetting of own forces ashore and afloat. When delivering illumination fire, the line of fire must be so adjusted with relation to our front lines that friendly troops are not endangered by star-shell bodies. Except in rare instances, searchlight illumination for troop support is generally unsuccessful; it almost invariably draws enemy fire on the ship employing it.

7. *Requirements for neutralization.* The volume of fire required for neutralization of an area is difficult to establish. The standard volume established prior to World War II prescribed the equivalent of sixteen 75-mm projectiles per minute per 100-yard square as being sufficient for neutralization. Although the experiences of World War II showed this to be entirely inadequate in many instances, it is still a valuable guide which may be modified as conditions dictate. Experience proved that the blast effect of bursting projectiles had been highly overrated in neutralizing effect; it was found instead that neutralization primarily depended upon the casualties produced or threatened by flying fragments. Fragmentation effects vary greatly, even in the case of projectiles which are identical, because they depend upon such factors as angle of fall and terminal velocity. For example, the number of casualties inflicted may double with an increase in angle of fall from 10° to 60°. The effectiveness of fire for neutralization will also vary in accordance with the terrain, the types of enemy installations, and the quality of the enemy troops. Extensive studies of neutralization effects in World War II are being made in an effort to establish a new and more accurate neutralization factor.

8. *Target intelligence.* Before undertaking any bombardment of land targets, a thorough familiarity with the terrain and hydrographic features of the objective, and with the location of profitable targets, must be acquired. The study of available charts, maps, aerial photographs, radar PPI simulations, mosaics, and other pertinent information will be necessary for rapid, effective troop support. Normally these charts, maps, photographs, and target information will be furnished each fire-support ship prior to the operation. The systematic destruction of defenses requires the continuous assembly and evaluations of targets known beforehand, and of those discovered in the course of the operation. Damage assessment must be based upon visual observation and photo-analysis. A common error is over-optimism as to the effectiveness of naval fire against land targets.

9. *Military Grid Reference System.* Rapid and accurate means for designating the location of targets is an essential feature of naval gunfire support. It

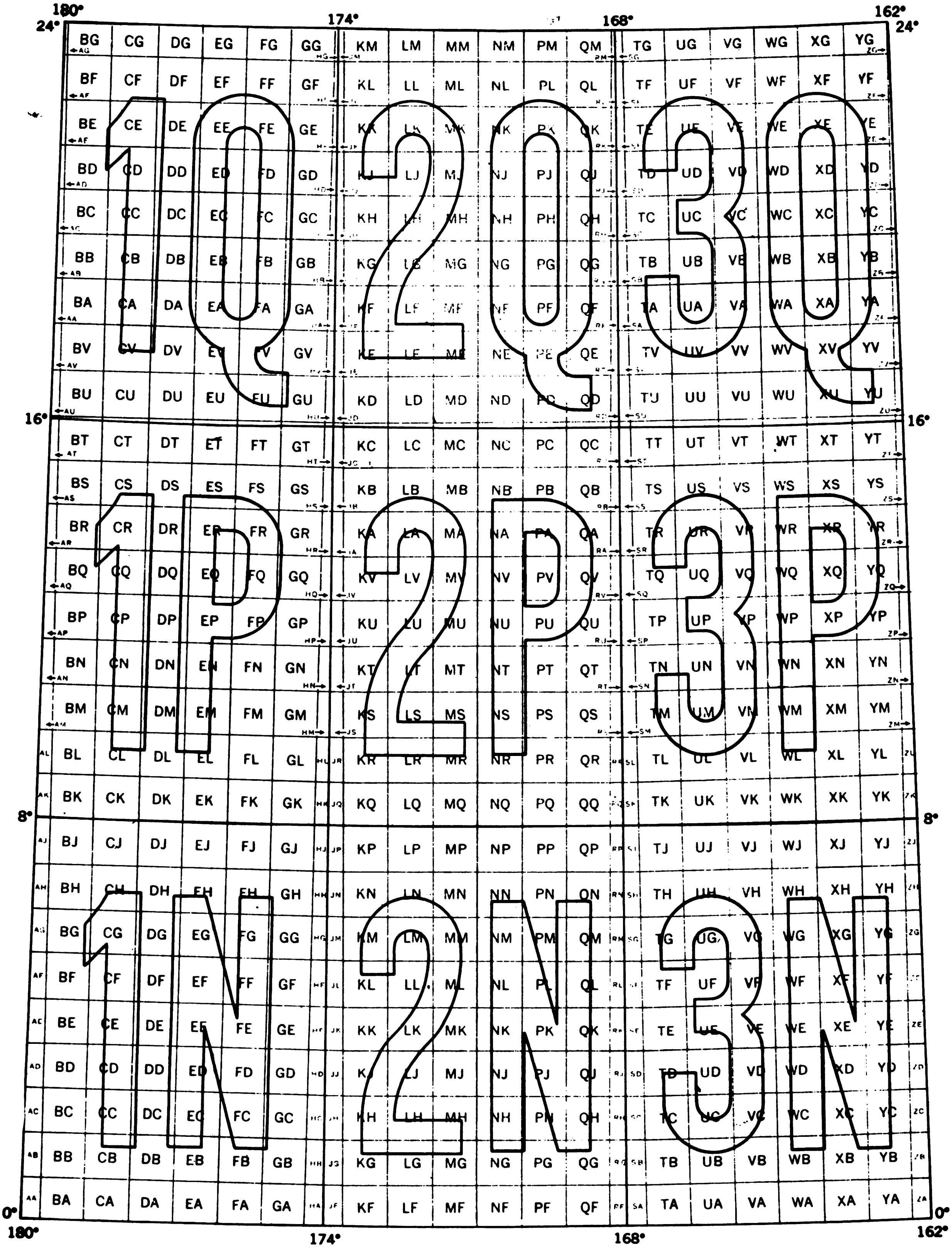


FIGURE 22B3.—Basic plan of the 100,000-meter square identification of the Military Grid Reference System.

should be obvious that the troop unit supported and the supporting ship must use a common map. Although they need not be of the same scale, and seldom are, the target maps must be identical regarding terrain features and the method of locating points thereon. Like other techniques of naval gunfire support, the development of a system of target location designations has passed through several stages, following generally a grid-system method. In this method, the land and sea areas at the objective are divided into squares by north-south and east-west lines, which are numbered. These lines are called grid lines.

The Military Grid Reference System imposes vertical and horizontal reference lines over a projection of the earth's surface. Its purpose is to simplify and to increase the accuracy of reporting and plotting in military operations. This grid reference system is based on two projections: the Universal Transverse Mercator (UTM), and the Universal Polar Stereographic (UPS).

a. Universal Transverse Mercator. Any projection is simply a method of depicting a spherical surface on a flat piece of paper. The familiar Mercator projection, long used in navigational charts, mathematically develops the surface of the earth on a cylinder which is tangent to the earth's surface at the equator. The *Transverse* Mercator uses the same principle, except that the cylinder is tangent to the earth's surface along the great circle of a meridian, at right angles to the equator. In the UTM, both meridians and parallels appear as slightly curved lines. See figure 22B3. There is very little distortion near the line of tangency, so that a relatively narrow band of longitude can be accurately shown from pole to pole.

Universal Transverse Mercator coverage is based on five separate spheroids which depict the earth from 80° south latitude to 80° north latitude. The spheroids are mathematically corrected to allow for the irregularities of the oblate spheroidal shape of the earth. When pieced together, the spheroids join each other on exact degrees of latitude and on exact even degrees of longitude.

Between latitudes 80° N and 80° S, the UTM grid divides the earth into areas 6° east-west by 8° north-south. Columns (6° wide) are numbered 1 through 60 consecutively, starting at the 180° meridian and proceeding easterly. Rows (8° high) start at 80° S and proceed northerly to 80° N. They are lettered alphabetically *C* through *X*, omitting letters *I* and *O*.

The method of identifying the 6° by 8° areas is called *grid zone designation*. Grid zone designation for any area established by the columns and rows is determined by reading right-up on the chart. As an example, column designation 2 and row designation *P* produce grid zone designation 2*P*.

Each grid zone designation is subdivided into 100,000-meter squares, as shown in figure 22B3. The 100,000-meter squares are also laid out in columns and rows, but *these are identified by letters only.*

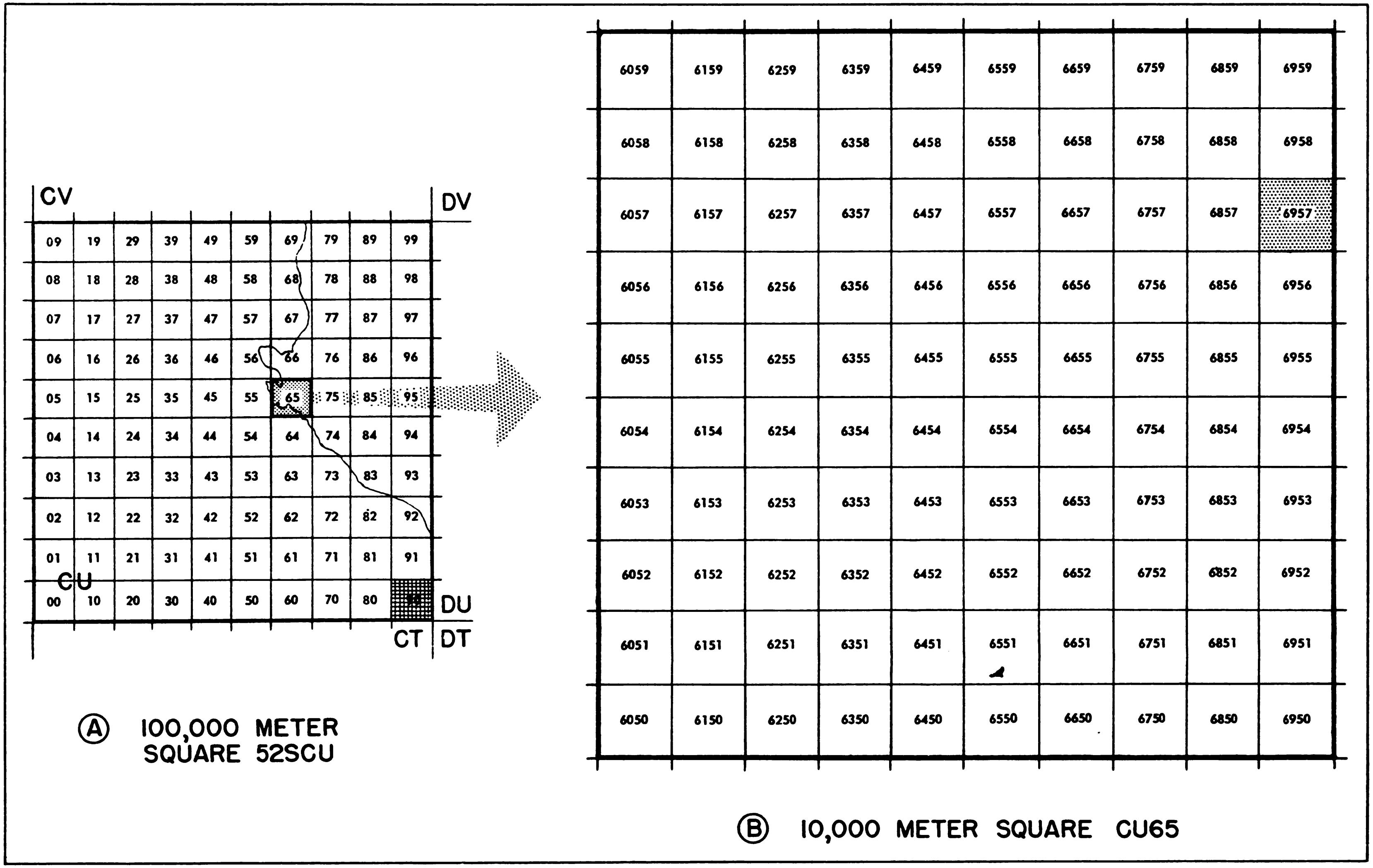
As shown in figure 22B3, the 100,000-meter squares are lettered without regard for boundaries of separate grid zones. Columns are lettered *A* through *Z* (omitting *I* and *O*) beginning with the 180° meridian and proceeding east along the equator. Since the 100,000-meter squares are established about the central meridian of each zone, UTM projection creates partial squares at the edges of each zone. The partial squares create partial columns which are included in the alphabetical progression just as though they were made up of complete 100,000-meter squares. In lettering the columns, the alphabet is repeated every 18°. Figure 22B3 shows a complete cycle of lettering.

The rows of 100,000-meter squares are lettered alphabetically from south to north, *A* through *V*, omitting *I* and *O*. The alphabet is repeated every 2,000,000 meters (20 squares). Squares having the same identifying letters are separated as follows: The row alphabet for each odd-numbered UTM zone begins at the equator; for each even-numbered UTM zone, it begins 500,000 meters south of the equator. Thus, squares carrying the same letters are effectively separated by 18° of longitude.

Location of a particular 100,000-meter square is determined by reading right-up, first the column letter and then the row letter. Thus, *MT* in figure 22B3 is found by reading right along the column letters to *M* and up the row letters to *T*.

Each 100,000-meter square is further divided to provide, eventually, a 100-meter square reference area. First, grid lines spaced 10,000 meters are placed within each square. Lines are placed vertically and horizontally so that their intersections form right angles. Since the grid lines form one hundred 10,000-meter squares, only two digits are required for designation 00 to 99. Designation of the 10,000-meter squares begins in the lower left corner of the 100,000-meter square. The 10,000-meter square in this corner is designated 00; the one immediately above is 01, the next 02, and so on until the top square in the upper left corner carries 09. The square immediately to the right of square 00 is 10, the next is 20, and so on to 90, the square in the lower right corner of the 100,000-meter square. In other words, the 10,000-meter squares are numbered *up* each column from the 00 column to the 90 column.

Each two-digit 10,000-meter square is further divided into 100 squares by placing grid lines at 1,000-



09	19	29	39	49	59	69	79	89	99
08	18	28	38	48	58	68	78	88	98
07	17	27	37	47	57	67	77	87	97
06	16	26	36	46	56	66	76	86	96
05	15	25	35	45	55	65	75	85	95
04	14	24	34	44	54	64	74	84	94
03	13	23	33	43	53	63	73	83	93
02	12	22	32	42	52	62	72	82	92
01	11	21	31	41	51	61	71	81	91
00	10	20	30	40	50	60	70	80	

6059	6159	6259	6359	6459	6559	6659	6759	6859	6959
6058	6158	6258	6358	6458	6558	6658	6758	6858	6958
6057	6157	6257	6357	6457	6557	6657	6757	6857	6957
6056	6156	6256	6356	6456	6556	6656	6756	6856	6956
6055	6155	6255	6355	6455	6555	6655	6755	6855	6955
6054	6154	6254	6354	6454	6554	6654	6754	6854	6954
6053	6153	6253	6353	6453	6553	6653	6753	6853	6953
6052	6152	6252	6352	6452	6552	6652	6752	6852	6952
6051	6151	6251	6351	6451	6551	6651	6751	6851	6951
6050	6150	6250	6350	6450	6550	6650	6750	6850	6950

FIGURE 22B4.—Area 6957 within square 65.

meter intervals, vertical and horizontal, perpendicular at the crossings. Designation of the resulting 1,000-meter squares requires four digits. Two of the four digits are taken from the 10,000-meter square in which the particular 1,000-meter square is located. For example: In the 1,000-meter square designated 6957, digits 6 and 5 are keyed to the 10,000-meter parent square, 65. Figure 22B4 shows the location of area 6957 within square 65. Actually, area 6957 is square 97 within the 10,000-meter square 65.

For accuracy in pinpointing targets, it is necessary to break down further the 1,000-meter squares. Formerly, a system called *target area designation* (TAD) was used for this purpose. Each 1,000-meter square was divided by grids at 200-meter intervals, making twenty-five 200-meter squares, labeled *A* through *Y*. The lettering started at the upper left corner of the square, and the alphabet progressed row by row across, finishing at the lower right corner of the square. Under this system, a 200-meter square could be designated by adding the letter to the four-digit 1,000-meter square. For greater accuracy, the individual 200-meter square was broken down into areas designated by numerals 1 through 5, providing enough accuracy for the spotter to adjust salvos to hit the target.

The U. S. Navy Hydrographic Office no longer prints the 200-meter grid lines, the TAD instructions, or the letter designation for the 200-meter squares on grid charts. Since this is fairly recent policy, charts bearing this system will probably be issued until the present supply is exhausted. However, the TAD system is no longer authorized for U. S. Navy use, and reference to it on available charts is to be ignored.

The authorized method for reducing the reference area to a 100-meter square requires six digits. To illustrate, consider the previous example where the 1,000-meter square was 6957. Adding two digits divides this area into tenths, or 100-meter squares. Thus, in the designation 69*3*57*8*, the two additional digits (3 and 8) mean three-tenths (300 meters) east from the southwest corner of the 1,000-meter square 6957, and eight-tenths (800 meters) north from the southwest corner of the square. The *east* distance is always placed between the second and the third digits of the 1,000-meter designation, and the *north* distance is placed at the end. In the final figure, 693578, observe that the first three digits indicate distance east of the southwest corner of the original 100,000-meter square, and the last three digits indicate distance north of the southwest corner.

A military grid reference consists of a group of letters and numbers which indicate (1) the grid zone designation, (2) the 100,000-meter square identification, and (3) the grid coordinates; that is, the numerical reference of the point expressed to the desired accuracy. Examples:

52*SCU*	locating a point within a 100,000-meter square.
52*SCU*65	locating a point within a 10,000-meter square.
52*SCU*6957	locating a point within 1,000 meters.
52*SCU*693578	locating a point within 100 meters.

As a matter of practical referencing in a shore bombardment problem, both the grid zone designation and the 100,000-meter square identification are generally omitted. The grid reference box shown as a part of the marginal data of every chart specifies the maximum distances beyond which omissions in reporting are not permitted.

b. Universal Polar Stereographic. The projection used for the polar areas is the polar stereographic covering the limits from 80°N to 90°N for the north polar area, and 80°S to 90°S for the south polar area. The system for griding the poles is called the *Universal Polar Stereographic.*

Stereographic projection is conformal, but instead of the plane for projection of the area being tangent to the pole, for the UPS system, it is parallel to the plane of the equator, cutting through the latitudes 81° 07′ north and south. With the plane at this area, a minimum variation of scale is obtained over the entire UPS system.

The north polar area is divided into two parts by the 180° and 0° meridians, the half containing the west longitudes identified as zone *Y* and the half containing the east longitudes as zone *Z*. The south polar area is similarly divided along the 0° and 180° meridians, the west longitude half identified as zone *A* and the east longitude identified as zone *B*.

In the north polar area the 180°–0° meridians coincide with an even 100,000-meter vertical grid line and the 90° W–90° E meridians coincide with an even 100,000-meter horizontal grid line. Grid north coincides with the 180° meridian from the pole. In grid zone *Y*, the 100,000-meter columns (right-angle lines to the 90° W–90° E meridians) are labeled *J* through *Z* (*I* and *O* omitted), alphabetically from left to right. In grid zone *Z*, the 100,000-meter columns are labeled *A* through *R* (omitting *I* and *O*), alphabetically from left to right. Letters *D, E, M, N, V,* and *W* are omitted to avoid confusing the 100,000-meter squares with those of the adjoining UTM zones.

Starting at the 80° parallel and reading toward grid north, the 100,000-meter *rows* (at right angles to the 180°–0° meridians), are labeled *A* through *Z* (omitting *I* and *O*).

Identification of the 100,000-meter squares is accomplished by reading *right-up,* first the column letter followed by the row letter.

For the south polar area the plan is similar, except that grid north is coincident with the 0° meridian from the pole. Zone *A* at the south pole is equivalent to zone *Y* at the north pole, and zone *B* is equivalent to zone *Z*.

The 100,000-meter squares are subdivided into 10,000-meter and 1,000-meter squares in the same manner as the UTM system breakdown, and grid values are *always* read right-up.

Fire-support ships are provided with approach charts and bombardment charts for use on their dead-reckoning tracers. These charts are complete in hydrographic as well as topographic detail, and both have a grid system overprinted on them. These charts are of particular use in the delivery of indirect fire, and will be discussed later.

22B6. Shipboard problem of naval gunfire support

1. *Direct fire.* Targets which are visible from the firing ship offer the simplest fire control problem to the ship, and their destruction is easier than those targets which require indirect fire. When the target can be seen, the director can furnish accurate target bearing and elevation. These, with a present range which can be measured, ensure an accurate fire control set-up which should result in early hits. Direct fire is controlled as it would be for fire against enemy ships except that (1) at short ranges better accuracy may be obtained if the gun pointers control gun elevation and firing and (2) when the ship is providing call fire support, the fire will be directed, controlled, and spotted by the shore spotter.

2. *Indirect fire: use of bombardment chart.* Given an accurate bombardment chart, and knowing the exact position of own ship, it is possible to measure off range and bearing to any land target that has been designated in advance and to hit the target without using directors or rangefinders.

The ships' position is accurately determined by navigational methods, using positively identified landmarks, and is plotted on the bombardment chart. Since own ship's course and speed are known, future positions may be projected ahead along the ship's track by dead reckoning. A future position, usually one minute ahead, is chosen, and from this point bearing and distance to the designated target are picked off the chart. These values of target range and bearing, together with own ship's course and speed, are set into the rangekeeper or computer which is being used to generate the solution. Target speed is set on zero. During this period, the time motor is off. When the ship passes through the position chosen, "Mark" is given by the plotter and the time motor of the computer is turned on. The computer should now generate present values of target range and bearing that agree with the actual measured values. These values, together with a fixed setting of altitude, based on the actual height of the target, are used to make up gun orders to hit the target. At stated periods, usually every minute after the initial set-up, "Mark" is given and the computed values are compared with the measured values. If they do not agree, since the target is motionless, the error must be due to some factor affecting the position of the ship. The set and drift of the current will cause such variation, and corrections for this effect may be compensated by introducing the drift and set of the current as target speed and reverse of target course respectively. At any time after the computed solution agrees with the measured values, the initial ballistic can be applied, and fire opened on the unseen target.

3. *Indirect fire: Point OBOE method.* This method of indirect fire was devised primarily for older ships with fire control systems and rangekeepers incapable of correctly generating range and bearing to a designated grid point. Its use, however, even by the newest ships is advantageous under certain conditions such as when no shore spotter or air spotter is available for observing the fall of shot. The method requires a visible point of aim (designated "Point OBOE") near the target, as well as the accurate location of the target and Point OBOE on a map.

In practice, the director line of sight is kept continuously trained and ranged on the point of aim (Point OBOE) to give a continuous range and bearing solution to this point. Salvos are initially fired at Point OBOE as a check on the gun ballistic, and as soon as

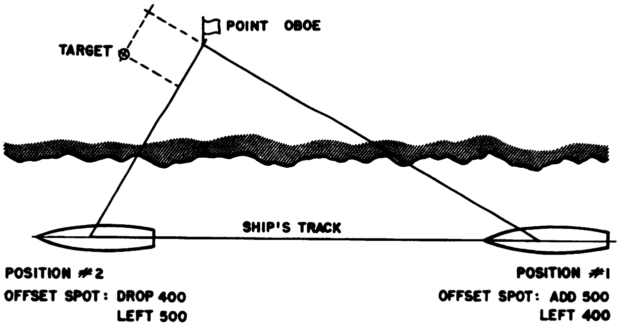


FIGURE 22B5.—Point OBOE method of indirect fire, showing necessity for continuous changes in offset spot to hit target.

the mean point of impact has been spotted to hit, range and deflection spots necessary to hit the invisible targets are applied. Point OBOE should be selected so that the limits of the spot dials do not have to be exceeded to reach desired targets.

Since the motion of the firing ship continuously changes the values of the offsets from the point of aim, frequent changes in these offset spots must be made to ensure hitting the target. This problem is illustrated in figure 22B5. One way to determine correct range and deflection spots continuously is to use a small transparent overlay on which are inscribed 100-yard squares drawn to the same scale as the chart. With the center of the gridded overlay on Point OBOE, and the grid lines oriented to the direction of the line of sight from the ship, range and deflection spots to hit the designated target may be read directly from the grid overlay.

4. *Indirect fire: functions of CIC.* The primary function of CIC in naval gunfire support is to keep an exact check on the ship's position and from this to determine ranges and bearings to targets designated for indirect fire. It can be readily appreciated that the accuracy of fire, when using the method previously described, depends primarily on the skill of the CIC team. CIC also keeps a record of own troop front-line positions, target locations, and other information pertinent to the support of the troops ashore. It acts as the clearing house for information to and from the shore fire control party and air observer, with whom it has direct voice radio communication. Thus in naval gunfire support, CIC keeps the ship's commanding officer, gun control, and plot advised regarding the requirements for support; furnishes the information necessary to provide the support; and gives the shore fire control party such information as may be necessary or useful. In addition to target range and bearing, CIC must determine, from contour lines of the bombardment chart, the elevation of the target above sea level and send this to the plotting room so that range error resulting from this elevation may be corrected in the computer.

On heavy ships (battleships and cruisers) the above functions of CIC are often performed in a section of the plotting room. This leaves the ship's CIC free for the other vital duties it must perform.

5. *Special fire control problems of naval gunfire support.* Targets which are located on the far slope of a hill or similar terrain feature lying between the firing ship and target present a particularly difficult problem to the flat trajectory of naval gunfire. This problem (defilade fire) requires obtaining an angle of fall which will clear the crest of the hill and be steep enough to hit the target beyond. When this situation occurs, the angle of fall is chosen which is greater than the angle of the reverse slope. Two solutions are then available. The ship may either increase the range to obtain the angle of fall selected, or it may use reduced-velocity charges at the shorter range to obtain this selected angle of fall. In figure 22B6, which illustrates this problem and its solutions, *A* is the trajectory produced by standard service charges and is too flat; *B* is the trajectory which can be obtained by using reduced-velocity charges; *C* is the trajectory which can be obtained with standard service charges by increasing the range.

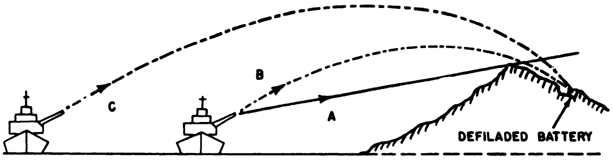


Figure 22B6.—Problem of hitting a defiladed target.

In the event it is necessary to fire over friendly troops occupying an elevated position between the firing ship and the target, it is necessary to determine the elevation of the target, the elevation of the troop position, and the differences between the two. Call this difference y, and the horizontal distance between the troop position and the target x. By referring to trajectory curves, you can determine the range at which the abscissa x yards from the point of impact is safely greater than the difference in elevation y. This is the limiting range outside of which it is safe to fire.

22B7. Spotting by target grid system

Spotting, as it applies to naval gunfire in general, was discussed in chapter 18. All the general principles contained therein apply in shore bombardment spotting, but additional considerations apply also, especially when spots are to be made by a shore fire control party.

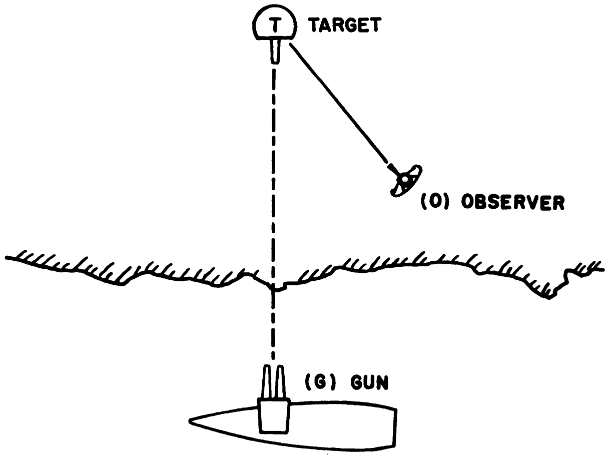


Figure 22B7.—Target-grid spotting problems.

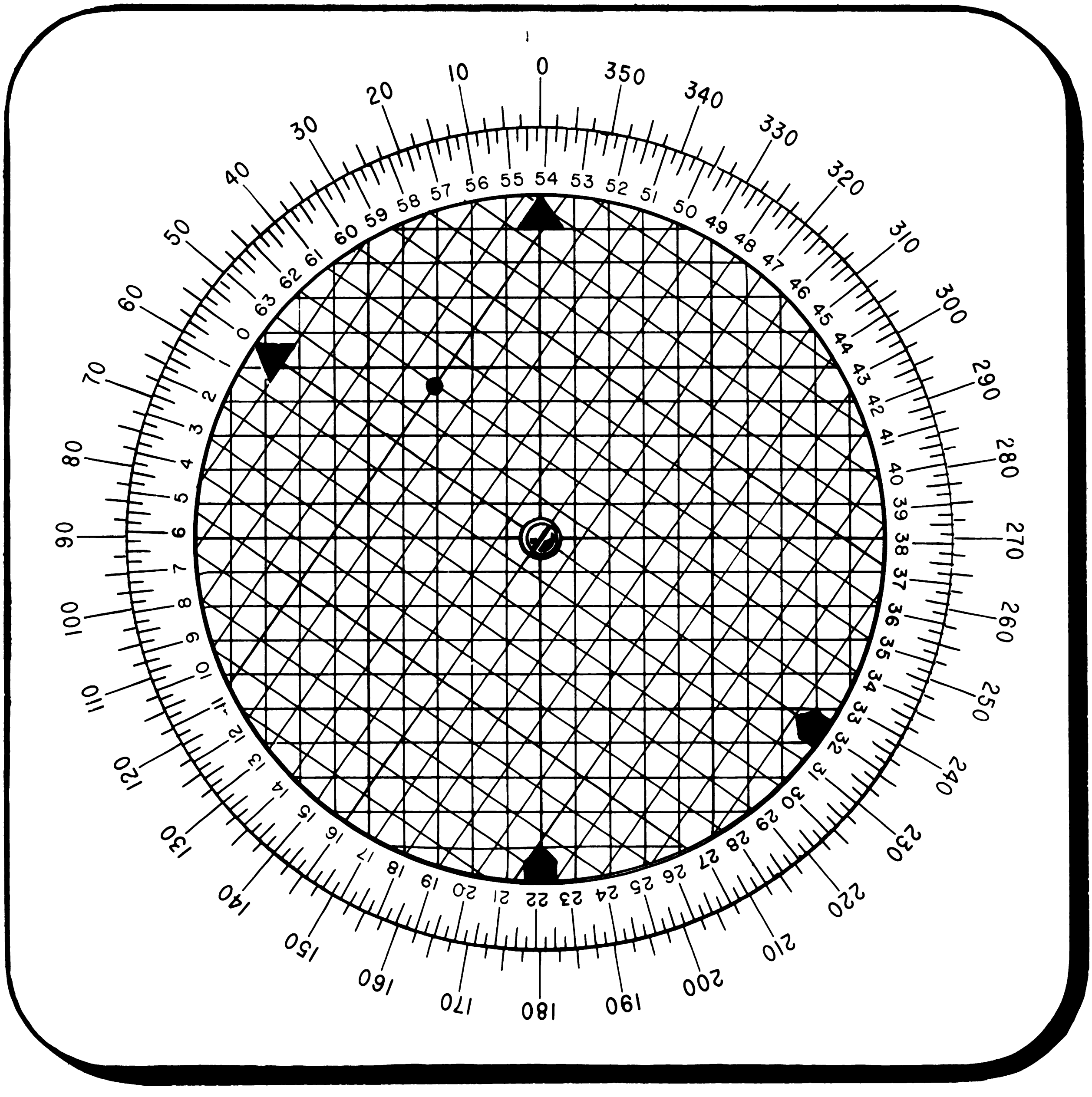


Figure 22B8.—Grid spot converter.

A spotter ashore must be advantageously located to observe the fall of shot. In most cases this requires that he be as close as possible to the enemy positions which will have to be taken under fire; this presents him with a very serious front-line problem of survival.

Spots made by an observer aboard the firing ship are naturally oriented to the line between the firing ship and target (called the gun-target line). Spots made from aircraft can be oriented readily to the gun-target line, since both the gun and the target are normally within the aircraft observer's field of vision. But spotters ashore are frequently unable to see the firing ship and, so long as they were required to make their reports in relation to the gun-target line, this seriously limited the value of the information sent by the spotter to the ship.

To simplify this problem for the spotter, the Army Artillery School at Fort Sill developed the target-grid system for use in spotting the fall of shot on land. As a result of trials in joint exercises, the target-grid system has been incorporated into the Standard Spotting and General Shore Bombardment Procedure for use within the naval service.

The objective of this system is to permit the observer to spot the fall of shot just as he sees it along his own line of sight to the target, called the observer-target line, irrespective of the position of the firing ship and of the gun-target line. The procedure is briefly outlined as follows (refer to fig. 22B7).

1. The observer, in his call for fire must give the azimuth from himself to the target; direction OT in the illustration.
2. The observer makes all his observations and corrections with respect to the observer-target line (OT).
3. The CIC or plotting room crew converts the corrections of the observer to corrections with respect to the gun-target line (GT).
4. The plotting room crew introduces into the rangekeeper (computer) the spots corrected to the gun-target line.

22B8. Grid spot converter

The *grid spot converter* is a device used to convert graphically the corrections given by the spotter from the OT line (spotter's line of sight) to the GT line (ship's line of fire). It consists of two superimposed concentric circles with horizontal and vertical lines etched on them, forming squares, each dimension representing 100 yards. The lower circle is etched in *black* on the face of the converter; it is stationary. Its circumference is graduated counterclockwise in *degrees* from 0° to 360°, with 0° at the top. The 0—180 diameter of this circle is a *black arrow,* with the arrowhead at zero degrees.

The upper circle is etched in *red* on a movable, transparent plastic disc; this disc is mounted concentrically over the lower circle, so that it is free to rotate about its center. The circumference of the upper disc is graduated counterclockwise in *mils* from 0 to 6,400, with 0 mils at the top. The 0—3,200 diameter of this disc is a *red arrow,* with the arrowhead at zero mils. The lower disc is the *own ship* disc, and the black arrow represents the GT line. The upper, movable disc is the *observer* disc, and the red arrow represents the OT line.

The grid spot converter is used as follows (see fig. 22B8):

1. The converter operator obtains the true azimuth of the GT line in degrees by reading the true target bearing on the own-ship dial group of the computer. He makes a mark with a grease pencil at this azimuth on the lower (black) disc. He then obtains the azimuth of the OT line from the observer (spotter) *via* CIC. He makes another mark at this azimuth on the upper (red) disc.
2. The operator then rotates the upper disc until the two pencil marks are opposite each other. (In the figure, GT is 140° and OT is 1,500 mils. See "pencil marks.") The red and black arrows now indicate the angular relationship of the observer's line of sight and the ship's line of fire.
3. When a spot is received from the spotter, the operator starts at the center of the upper disc, which represents the *burst,* and plots "Right 200; add 500" along the lines perpendicular to and parallel to the red arrow. The point plotted then represents the *target,* which is marked with grease pencil. He now goes back to the burst (center) and counts off the squares to the target, on the lower disc, perpendicular to and parallel to the black arrow. This gives a spot of "Left 300, add 450," which is relative to the ship's line of fire. This is the spot which is applied to the computer (L300 is in yards, and must be converted to mils before it can be applied).

Chapter 23

AIRCRAFT FIRE CONTROL

A. Introduction

23A1. Functions of aviation ordnance

It has become virtually axiomatic that command of the air over the sea is requisite to control of the sea. The modern air arm can be utilized with great versatility and tactical surprise. In World War II the fast carrier task force proved itself a formidable contender, capable of gaining quick control of vast sea areas. Planes on fast carriers include fighter types armed with automatic guns, bombs, and rockets; night fighters; attack planes designed to carry aerial torpedoes, bombs, or rockets; and high-speed photographic planes.

Other planes adapted for special purposes are also utilized by the modern Navy. Missions required of the naval air arm include destruction of enemy air arm, ships, personnel, transport, and installations; antisubmarine assignments associated with the activities of hunter-killer groups; spotting gunfire; patrol, search, and rescue duties; minelaying; and transport of personnel and material. Aviation ordnance includes the weapons and ammunition that will ensure successful implementation of these missions.

23A2. History of aviation ordnance

In 1910 a wooden platform was erected over the bow of a Navy ship, from which a test pilot took off successfully. Shortly thereafter, the same pilot took off from a land base, landed on another platform that had been rigged on the USS *Pennsylvania,* took off again, and returned to base. Thereafter, Navy training of pilots became a reality, but the Navy air arm was small at the outbreak of World War I; it grew rapidly during the war period, and the Bureau of Aeronautics was established in 1921. The Navy's first carrier was the USS *Langley,* converted from a collier in 1922. Five years later the two carriers, the USS *Lexington* and the USS *Saratoga,* rebuilt on hulls originally intended for battle cruisers, joined the Fleet. Both of these aircraft carriers saw long and spectacular service. The *Lexington* succumbed to enemy attack in the battle of the Coral Sea, and the *Saratoga* lies at the bottom of Bikini Lagoon, having been sunk in one of the atom-bomb tests held there.

Airplanes were assigned tactical missions early in World War I, taking over reconnaissance and spotting duties that had previously been vested in moored or free balloons. At first, opposing pilots largely ignored each other in air encounters, but this peaceful state of affairs was not long maintained. It is said that one imaginative pilot took a load of bricks aloft one day, his purpose being to shatter the wooden propeller of an enemy plane. In retaliation, pilots began to carry pistols as protection against such threats, and observers were soon armed with rifles. In such manner the development of aircraft armament had its origin.

Small aerial bombs were used in the course of World War I. They were thrown from planes by pilots or observers, and were more effective from a morale standpoint than in terms of casualties produced or damage to enemy installations. In due course machine guns on free (flexible) mounts were installed in airplanes so located that a rear-seat observer could fire over the head of the pilot and the propeller arc. Then the German Fokker perfected a system wherein a fixed, forward-firing machine gun had a rate of fire so synchronized as to fire between blades of the propeller. The fixed, forward-firing gun quickly became a standard weapon, and has remained so to this day. The modern counterpart of the early free gun mount is the power-operated turret of a large bomber.

In the interim between World War I and World War II, a variety of weapons were perfected for airborne use. During World War II the military employment of such weapons was extended to include various automatic guns, torpedoes, bombs, guided missiles, rockets, and mines. Thus the utility of the air arm was greatly broadened. But progress has brought added problems. Aviation ordnance and gunnery have always been closely associated with

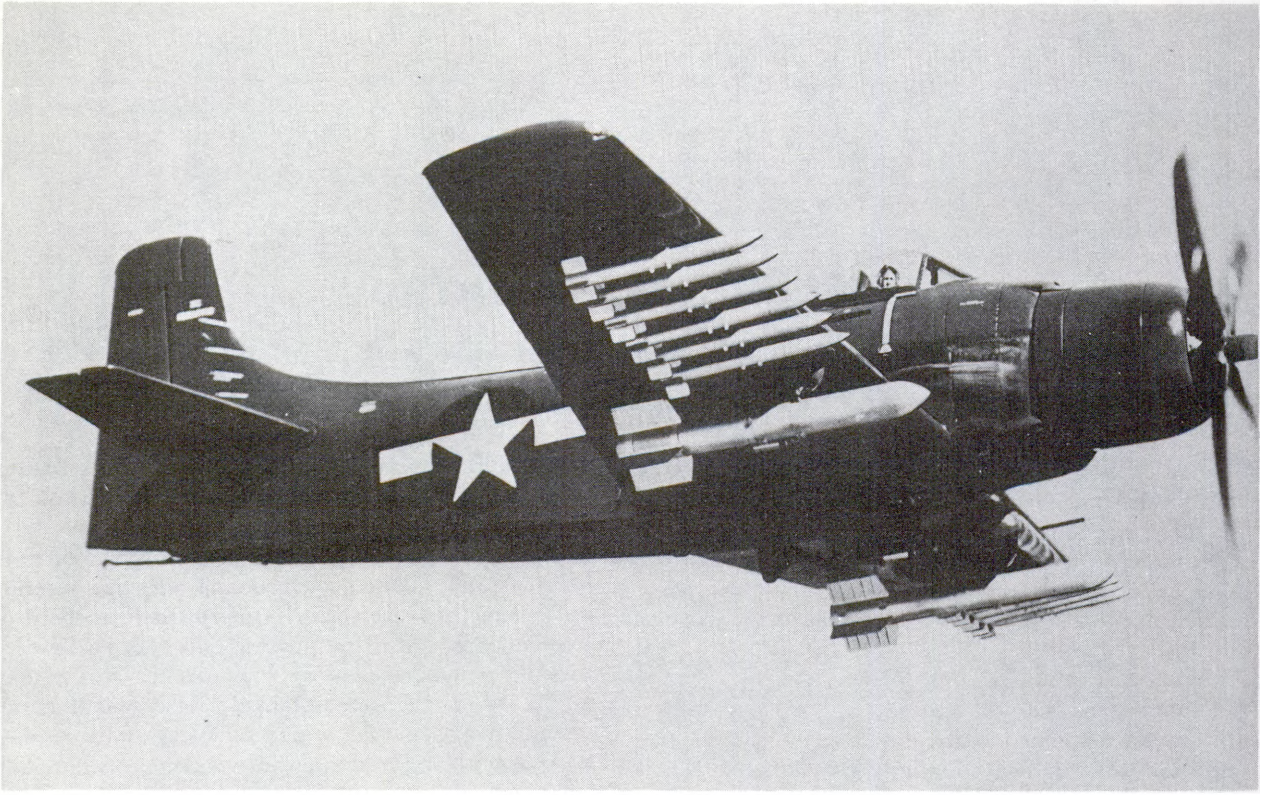


FIGURE 23A1.—AD "Skyraider" with full rocket racks.

changes in aircraft design and performance. By the end of World War II, great advances had been made in flight speed and ability to operate at high altitude. These improvements in airplane performance have created additional problems concerning the design and employment of airborne weapons. Conversely, improvements in aviation ordnance have introduced problems of aircraft design.

B. Aircraft Gunnery

23B1. The general problem of aviation gunnery

Because aircraft speeds are high and constantly tend to become higher, actual firing time in any attack is limited to seconds. For this reason it is essential that rate of fire be rapid, so that there is reasonable probability of scoring enough hits to do effective damage. High projectile velocity is also desirable, to reduce time of flight and thereby minimize the effect of many variables which tend to detract from accuracy. It must also be remembered that performance of the airplane itself is a factor in the effective employment of the plane's guns.

Recognition of targets is one of the most critical items in air combat, because it is the key to making initial estimates of range, speed, and mission. A common error in aerial gunnery is to open fire before the target comes within range, and to continue fire when the target is beyond effective range.

In fact, the general problems of aircraft gunnery can be reduced to questions of *who, where,* and *when.* "Who" refers to the problem of whether a potential target is friend or foe, and if foe, what the type of plane may be. "Where" is the problem of target location relative to the gun, which in modern installations may be solved or largely solved by automatic means. "When" is the problem of when to open and cease fire to provide maximum probability of obtaining hits, yet maintain necessary conservation of a limited ammunition supply.

A typical aircraft gun, the 20-mm automatic gun Mark 3, is discussed in chapter 9.

23B2. Types of aircraft turrets

Various types of aircraft turrets have been designed in view of the need for minimizing aerodynamic drag, and in view of the desire to provide an adequate arc of coverage at various locations on the aircraft. Three types of aircraft turrets are (1) the spherical or *ball* type, (2) the *cylindrical* type, and (3) the *teardrop* type. All three types may incorporate power drives consisting of amplidyne or thyratron units. They are shown in figure 23B1.

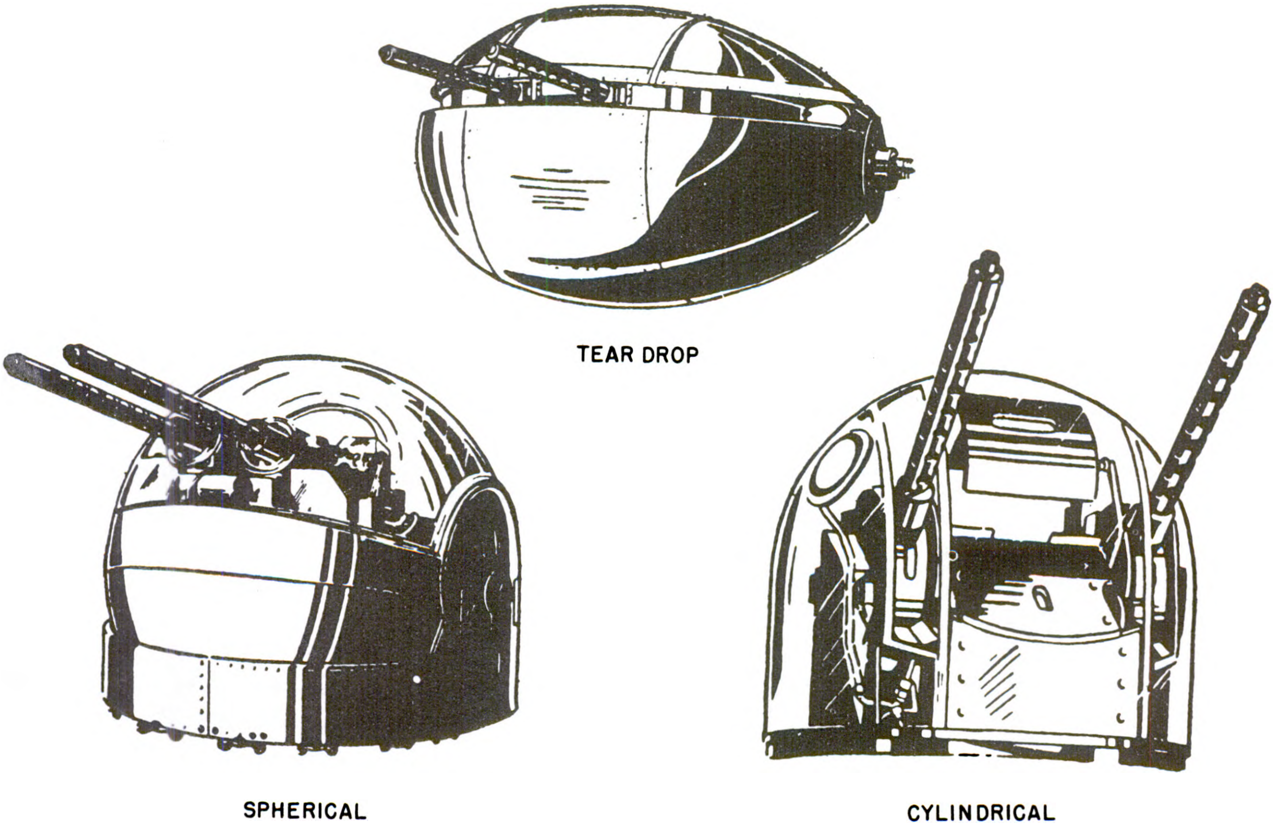
In the ball type of turret, the entire turret moves in train and elevation about axes which intersect at the center of the sphere. Such turrets are suitable for location in the nose, tail, or lower centerline of the aircraft. The cylindrical type of turret moves about its own axis in train, but only its guns and sights move in elevation. Such turrets ordinarily are located in the tail or upper and lower centerlines of the aircraft. The teardrop turret has a streamlined shape, with its axis, which is the chord of the streamlined arc, parallel to the fore-and-aft centerline of the plane. The teardrop type rotates about its own axis in elevation, but only the guns and sights move in train. This type is suitable for waist installation.

In larger airplanes, turrets are installed to provide full defensive coverage. Locations on various planes commonly include the nose, tail, upper and lower deck, and side waist positions. In high-speed planes there is a tendency to sacrifice frontal coverage in favor of good tail coverage, since attack is more probable in the latter area. In smaller planes, fixed, forward-firing guns may be relied upon to provide frontal coverage.

23B3. Fixed and free gunnery

Fixed, forward-firing guns comprise the primary armament of fighter and interceptor planes, semi-defensive armament on small attack-type planes that are fairly maneuverable, and accessory armament on some larger attack planes when strong gun concentration is desired for strafing. Such guns usually are aligned on the ground by a boresight technique, so that they coincide with the line of flight of the airplane under combat conditions. The angle of attack of the plane varies with its speed and other factors; however, variations in angle of attack within the range of combat speeds usually are not large enough to affect gunfire accuracy seriously.

If time of flight of the projectile were zero, it would merely be necessary to attack at the appropriate speed, point the plane at the target, and score hits. How-



TEAR DROP

SPHERICAL

CYLINDRICAL

FIGURE 23B1.—Types of aircraft turrets.

ever, since attack angle may vary and the projectile's time of flight to the target usually is in the order of 1 to 3 seconds, it is ordinarily necessary to make various allowances, such as lead provided to compensate for target motion. Maximum lead is required when the attacking plane is on the beam of the target.

The problem of fire control for free guns is somewhat more complex. This is because the free gun is not aligned with the air stream past the plane, but may take an infinite number of angles thereto. In addition to correcting for target speed and course, it is necessary to correct for own ship's velocity vector relative to the gun position. The use of simple ring sights (noncomputing) has proved to be fairly effective in fixed, forward-firing gunnery, but is largely ineffective in free gunnery except at point-blank ranges.

23B4. Sights used in aerial gunnery

At the beginning of World War II, noncomputing *ring sights* and *telescopic sights* were in common use. They proved to be relatively inadequate, especially in the case of free gunnery, because pilot or gunner had to estimate both range and deflection. Introduction of the *illuminated reflector* sight partially solved the problem. In this sight a lighted reticle is focused on infinity, and appears superimposed on the target, which is viewed by pilot or gunner through a transparent reflector plate. This sight made it possible to view the target readily, day or night, and permitted unrestricted movement of the head without introducing parallax. But the pilot or gunner still had to estimate his lead.

In the course of World War II, several types of *lead-computing sights* were developed, all based upon the use of a gyroscopic element to measure angular movement of the line of sight between gunner and target and thus make possible the introduction of the proper lead angle. This type of sight is used on both fixed and free gun mounts. It includes a collimated reflector-type sight, and a gyro-controlled reticle superimposed on a fixed, boresighted reticle. Manual inputs include range and wing span of target. Own altitude, own air speed, and relative angular velocity of the target are computed automatically. Once wing span of the target has been estimated and set in, the gunner keeps the target framed in the gyro-controlled reticle, using his range input to control the size of the reticle. The gunner must keep the target in the reticle and track smoothly, so that gyro precession incident to the tracking, modified by automatic inputs and ballistic corrections, will provide the proper lead. The principle of the lead-computing sight is discussed in chapter 26, the Mark 15 sight described therein being closest in operating detail to those described below and in volume III, chapter 2.

The Gun Sight Mark 23 (see fig. 23B2) is a lead-computing sight designed for use with fixed, forward-firing guns. It omits components which compute windage and the effect of own plane's motion. It is effective in straight runs, but does not provide for centrifugal-force effects incident to aircraft maneuvers.

A typical lead-computing sight designed for free guns is described in volume III, chapter 23.

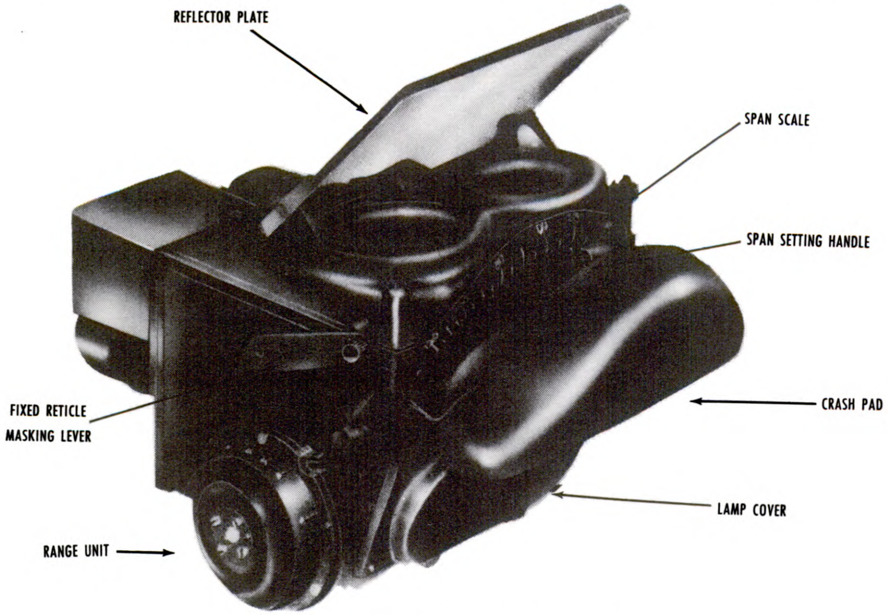


FIGURE 23B2.—Gun Sight Mark 23.

23B5. Tactical employment of aircraft guns

The tactical use of aircraft guns differs, depending upon whether primary armament of the plane consists of fixed, forward-firing guns on the one hand, or free guns on the other. Tactical use, however, is not exclusively dependent upon armament. In any case, it is virtually essential that personnel be able to recognize an enemy target as to type, and make a reasonably accurate estimate as to range.

The primary mission of fighter-plane groups often is the interception and destruction of enemy bombers before the latter have opportunity to reach their targets. The situation may be complicated by the presence of an enemy fighter escort for protection of the bombers, which necessitates either an initial attack upon the fighter escort, or simultaneous attack upon escort and bombers. In attacking a bomber, the pilot of a fighter plane with fixed, forward-firing guns is faced by the fact that position at the time the gunnery run is begun is of utmost importance. The plane, pilot, and guns act as one coordinated weapon, which must be properly positioned from the beginning to the end of the run.

Good initial position for attack upon a bomber includes altitude advantage, a location in advance of and to one side of the target, so that the pilot has a good view of the target, and enough maneuvering space to permit turning to close range and arriving at an open-fire point 20° to 30° forward of target's beam. Such a position is advantageous in intercepting jet bombers when the speed differential between bomber and fighter is small.

The breakaway after an attack should be as rapid and decisive as possible, because during this period enemy gunners have a chance to fire at the fighter plane unopposed. Ordinarily, however, the attack upon a bomber is not made by a single fighter plane, but is a coordinated attack made by several planes. Some of these planes may be able to make firing runs unopposed, because defending gunners are otherwise occupied.

From the standpoint of bomber defense, some advantage is gained by flying in close formation, because fire from several planes can then be concentrated upon a single attacker. Ordinarily the plane commander designates the sector to be covered by each gunner. In most circumstances fire is withheld unless direct attack is made upon own plane, due to the necessity of conserving ammunition.

Fighter-to-fighter combat, if conducted by only two opposed planes, is generally a series of maneuvers designed to gain position in the tail cone of the enemy, where he is undefended. Such encounters put a premium upon airplane maneuverability and pilot skill. The more common tactical approach is coordinated attack by a number of planes designed to take the enemy by surprise, and to establish local, even though temporary, superiority of numbers. Altitude advantage, a position up-sun from the enemy, and a position forward from the enemy, or in the direction he must go to complete his mission, are factors predisposing to success.

C. Theory of Horizontal Bombing

23C1. General

Study of the action of a bomb in air must be started from some situation with which we are familiar. The condition selected for a start, therefore, is the bomb's action when dropped in a vacuum. The established laws of physics give us formulas for the speed of a falling body, which are expressed in terms of the attraction of gravity and the amount of time or the distance through which it acts. The body will pick up speed or accelerate at a constant rate known as the *acceleration of gravity.* At sea level this acceleration is about 32.2 feet-per-second per second and is called "*g*." The formulas for computing the speed of a falling body in a vacuum are:

Vv (vertical velocity) $=\sqrt{2gh}=8.02\sqrt{h}$.

$Vv=gt$.

Where: $g=32.2$.

$t=$ time of fall in seconds.

$h=$ distance body has fallen in feet.

Vacuum trajectory. Due to the fact that a bomb is always dropped from a moving airplane, the bomb in a vacuum would retain, during its time of fall, any horizontal motion imparted to it by the plane, and this motion would remain constant in magnitude and direction. If the aircraft did not alter its course or speed, the bomb would remain vertically below the plane as it fell and the plane would be directly over the point of impact when the bomb hit. The parabolic path that the bomb would follow when dropped from a moving plane is called the vacuum trajectory.

Vacuum range. If the atmosphere offered no resistance, the bomb would carry forward, in its flight from the point of release to the point of impact, a distance called the vacuum range, *i. e.,* $Rvac=V_ct_f$.

Where: $V_c=$ speed of closing, which is the equivalent of relative speed and takes into account the range component of any target motion.

$t_f=$ time of fall.

23C2. Range problem

Since, in fact, air does exert a resistance upon the bomb, it has the following important effects:

1. It decreases the vertical velocity at any instant and thereby increases the time of fall.
2. It causes the horizontal velocity to diminish and thus causes the bomb to trail behind the vertical from the plane.

The above effects vary with:

1. Shape, weight, and skin friction of the bomb.
2. Altitude.
3. Air speed.

Figure 23C1 illustrates the basic phases of the horizontal bombing problem and shows the difference between an actual and a vacuum trajectory. In using figure 23C1 the following definitions apply:

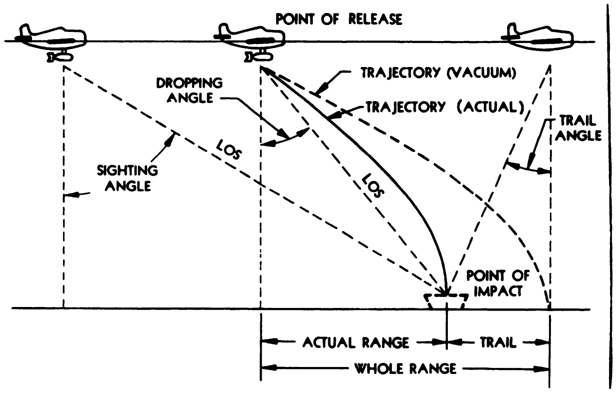


FIGURE 23C1.—Basic phases of the horizontal bombing problem.

1. *Sighting angle.* At any instant the angle between the LOS and the true vertical determined by the bomb sight gyro (spin axis).
2. *Dropping angle.* The angle between the LOS and the spin axis of the bomb sight at the instant of release. At this instant the sighting angle is equal to the dropping angle.
3. *Trail angle.* The angle between the spin axis of the bomb sight and the LOS at the time of impact, if the airplane maintains course and speed.
4. *Actual range.* The horizontal distance that the bomb travels between release and impact.
5. *Trail* (T). The horizontal distance between the points of impact of an actual trajectory and a vacuum trajectory.
6. *Whole range.* Equal to actual range plus trail.

Trail is primarily caused by the horizontal force (air resistance) acting on the bomb after release. Since the bomb is released in the direction of the plane's motion, the trail is always astern of the aircraft. The amount of trail is dependent upon two factors:

1. The amount of air resistance, which is equivalent to the indicated air speed of the plane at the time of release.
2. The length of time that air resistance acts on the bomb, which is equivalent to the altitude of release.

The actual trail and time of fall values for each type of bomb are determined at the proving ground and appropriate tables are prepared. Trail is always expressed in angular measure (mils) and the amount of trail is called trail angle.

In section 23C1 it is shown that the range of a bomb in a vacuum equal $V_c t_f$. Since a bomb dropped in air lags one dropped in a vacuum by the amount of trail, then $R_{air}=V_c t_f - T$. The velocity of closing (V_c) is an algebraic addition of air speed, and range components of wind and target speed.

If we can determine the angle between the vertical and the LOS to the target for any condition of V_c, the point of release of the bomb for any conditions can be found. In the solution of the problem we know the vertical, which is established by a gyro in the bomb sight, we measure the value of altitude, and we know from tables the values of time of fall (t_f and trail (T)). V_c is the unknown which is measured by the bomb sight, using the above known quantities. In the process of measuring V_c the sight automatically solves the right triangle whose sides are altitude and $V_c t_f - T$, for the dropping angle.

23C3. Drift problem

Discussion to this point has been based on conditions of either still air or wind that is either up or down the plane's heading. Since bombing only up or down wind is not practical, the bomb sight is designed to bomb on any course regardless of wind. To do this, means are provided whereby the bomber may direct the pilot to steer a course which will cause the plane's track to pass through the proper position with respect to the target so that the bomb will hit.

When an aircraft is headed directly up or down wind, it is making good over the ground the course steered. On any other course, with the wind somewhere to the side, the course made good is not that steered, but a resultant of the plane's course and speed and that of the wind. The angle thus formed between the heading of the plane in the air and its direction of movement over the earth is known as drift angle.

It is obvious that any cross wind will act not only upon the plane but also upon the bomb after release, and compensation must be made. If the bomber were merely to direct the pilot to continuously head the plane for the target, the path over the ground would be constantly changing and eventually the plane would be headed into the wind, the drift angle would

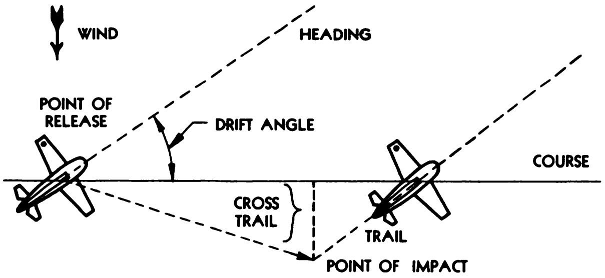


FIGURE 23C2.—Compensation for cross trail.

be zero, and the plane would pass directly over the target. With such a method the bombing problem is constantly changing and the bomber would never solve the problem correctly.

If the effects of a cross wind could be taken into account and the correct drift angle set up, the approach would be direct and constant, and the dropping angle could then be easily solved.

Establishment of the correct drift angle involves the setting up of a collision course with the target. The fact that the plane is flying horizontally above sea level does not introduce difficulties, for we can simply consider the plane's projection on the surface as being put on a collision course. This method does introduce a small lateral error known as cross trail, but it is compensated for in the bomb sight. This compensation causes the plane to be flown on a track to one side of the target by an amount equal to the value of cross trail. Figure 23C2 illustrates the necessity of compensating for cross trail.

The same consideration for target motion across the plane's heading is made as was for target motion along the heading in the range problem. It is considered as a cross wind and is absorbed as such in the bomb sight solution.

The solution of the bombing problem is done by the bomb sight in terms of angles rather than distances, and for this reason all values with the exception of altitude are put into the bomb sight as angles in the form of mils; a mil being the angle subtended by an arc whose length is one-thousandth of the range.

The above discussion concerned only horizontal bombing, which serves as a basic model for all types of bombing problems. It also concerned the use of the Mark 15 visual bomb sight. During and since World War II radar sights have been extensively employed. They present one great advantage; namely, that an attack is possible without visual sight of the target. An offset aiming feature in the radar sight makes possible the hitting of a poorly defined radar target by using some other well defined object as a reference point.

In horizontal bombing a compromise must be reached between low and high altitude of attack. Generally, low altitude provides maximum accuracy but gives minimum protection against interception and antiaircraft fire. High altitude gives better protection but less accuracy, and the target must be large enough to be vulnerable over a considerable area.

Horizontal bombing does not place undue stresses on the aircraft structure and therefore the plane is able to carry a comparatively large payload.

D. Other Bombing Problems

23D1. Dive bombing

In dive bombing the plane descends toward the target at an angle of 60 degrees or more, thus imparting considerable vertical velocity to the bomb at the moment of release. In a steep dive, with the bomb released at 2,000 to 6,000 feet, time of flight is short and air resistance, wind, and target motion are small. The problem of obtaining accuracy is simplified and a good percentage of hits can be obtained by use of a simple lead-computing sight. A fixed sight and rule-of-thumb methods may also be used.

The plane makes a good AA target, particularly as it pulls out of its dive. In recent aircraft, structural stresses are not too great and a large payload can be carried. Also advantageous is the adverse psychological effect on enemy personnel.

23D2. Glide bombing

Glide bombing is similar to dive bombing except that the attack angle is less than 60 degrees. This technique is better adapted to fighter-type aircraft which tend to develop excessive speeds in steep dives. Glide bombing is high-speed attack and bombs are released at an altitude of from 2,000 to 3,000 feet. Advantages over horizontal bombing include surprise and quick getaway. The disadvantages are that the bomb velocity is less than in dive bombing and AA vulnerability is greater than in dive bombing.

23D3. Skip bombing

In skip or masthead bombing the plane usually attacks at less than 500 feet and the bomb is dropped so close to the target that computation is simple and accuracy high. If the target is a ship, the bomb is released to hit near the warterline just before the plane pulls up to pass over the target. Delay fuzes are employed to give the aircraft time to clear the target. Surprise is highly desirable because the plane is exceedingly vulnerable to AA fire.

23D4. Toss bombing

Toss bombing is a technique wherein the pilot dives his plane directly at the target for a short time and then pulls out. The bomb is released automatically during pull-out, the pull-out maneuver giving the bomb additional forward velocity so that it is tossed above the original LOS and its trajectory intersects the original LOS at the target.

Bombs can be released at higher altitudes than with dive or glide bombing. It necessitates only a short bombing run, but the plane is within effective AA range and is vulnerable during pull-out.

Chapter 24

ANTIAIRCRAFT PROBLEM—ANALYTICAL

A. Target Positioning

24A1. Introduction

The antiaircraft fire control problem requires computations for its solution which, although more complex, are in many respects similar to those already considered in the surface problem. The same basic fire control problem must be solved, namely: present target position must be continuously determined; ballistic corrections, whereby the axis of the gun bore is offset from the LOS, must be computed; motion of gun platform must be corrected for; gun orders must be made up; and provisions must be made for correcting an inaccurate solution.

The air problem is more complicated than the surface problem because, as a result of target elevation (E), it is three-dimensional; it may require the use of time-fuzed projectiles; and the problem develops with much greater rapidity due to higher target speeds.

In order to simplify the presentation, certain factors in the analytical solution are described in a manner which does not exactly agree with the process carried out by a computer. For reasons of space and weight limitations, the automatic solution includes empirical expressions and mathematical short cuts which are not here discussed, as they do not contribute to the understanding of the analytical solution of the AA problem.

In this chapter the line extending from the gun to the advance target position is called the *line of fire* (LOF). The vertical plane containing the LOF is called the *plane of fire*. The actual flight of the projectile is from the own-ship position to the advance target position. In the surface problem ballistics were based on the LOS, while in the AA problem the change in target position during time of flight (Tf) of the projectile is of sufficient importance to warrant computing ballistics on the basis of the LOF. This section of the chapter deals with target position in the solution of the AA problem. Subsequent sections will take up ballistic computations and gun positioning.

24A2. Target position in relation to time

In considering target positioning, it should be noted that we are actually concerned with the target's position at *three distinct times:* (1) The present target position, (2) the target position at any given instant (generated target position), and (3) the target position at the end of a specific time, this specific time being Tf (advance target position).

24A3. Present target position

In the analytical solution, target position with respect to own ship is fixed by use of three coordinates: Present range (R), relative target bearing (Br), and target elevation (E). These quantities are illustrated in figure 24A1, and are defined as follows:

R *Present range.* The distance of target from own ship measured along the LOS.

Br *Relative target bearing.* The horizontal angle between the vertical plane containing the fore-and-aft axis of own ship and the vertical plane containing the LOS, measured clockwise from bow of own ship.

E *Target elevation.* The vertical angle between the horizontal and LOS.

Br and E can be determined by measuring the posi-

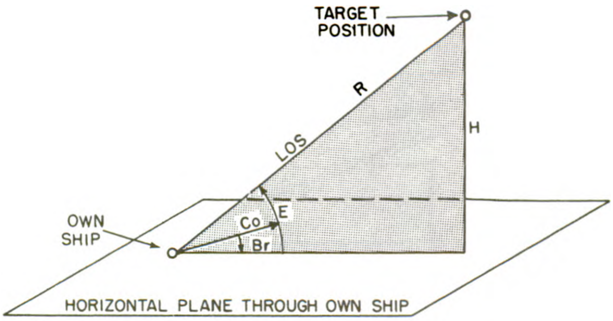


FIGURE 24A1.—Fixing target position.

tion of the LOS, while *R* can be measured by rangefinder or radar. As there is likely to be motion of own ship and target, successive instantaneous positions may be established by continuing to direct the LOS at the target and by measuring the present range.

24A4. Generated target position

In the equipment under discussion, present *relative* target position is generated by rangekeeper methods similar to those employed in the surface fire control problem. Generated relative target position is then used as the basis of the solution for sight angle (*Vs*), sight deflection (*Ds*), and fuze-setting order (*F*).

The generated target position can be expressed by the following formulas:

$$cR = jR + \Delta T(dR) = jR + \Delta cR.$$
$$cBr = jBr + \Delta T(dBr) = jBr + \Delta cBr.$$
$$cE = jE + \Delta T(dE) = jE + \Delta cE.$$

The initial values of *R, Br,* and *E* are obtained by measurement. Increments of time (ΔT) can also be considered as a measured quantity. This leaves the three rates, range rate (*dR*), *angular* bearing rate (*dBr*), and the *angular* elevation rate (*dE*) to be determined. This is done in two steps:

1. Resolve own ship's motion into horizontal components and target's motion into horizontal and vertical components of relative target motion.
2. Then resolve these horizontal and vertical components into three rates *dR, dBs,* and *dE* with respect to the LOS.

Resolution of own ship's motion is accomplished exactly as in the surface problem. Ship's motion is in the horizontal plane. Aircraft target motion cannot be resolved entirely into the horizontal plane, as the target may be climbing or diving.

In figure 24A2 the vector representing target motion is labeled *S,* is with respect to the earth, and is resolved into two components, horizontal target speed (*Sh*) and vertical target speed (*dH*), (called rate of climb and would be negative if target is descending). *Sh* and *dH* are the horizontal and vertical components, respectively, of *S*.

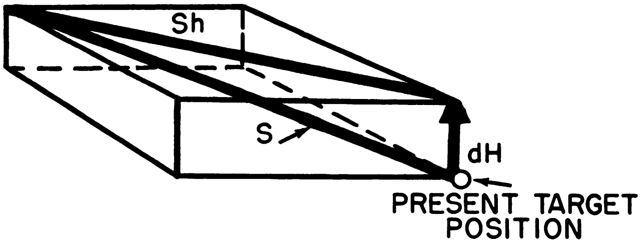


FIGURE 24A2.—Vector representing target motion.

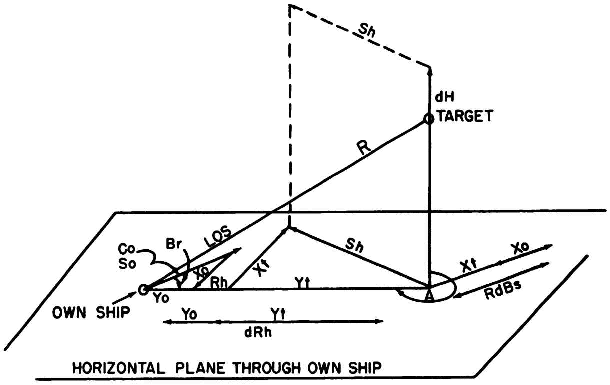


FIGURE 24A3.—Relative target motion and resolution. (Not to scale.)

In figure 24A3, *Sh* and *dH* are combined with figure 24A1, and these motions are resolved in the horizontal.

The LOS projected into the horizontal is called horizontal range (*Rh*). The horizontal range rate (*dRh*) is measured along this line. The linear deflection rate (*RdBs*) is measured at right angles to the vertical plane containing the LOS, and is measured in the slant plane through the LOS at the target. The complete solution for these last two mentioned rates (*dRh* and *RdBs*) follows. Both own ship's speed (already in the horizontal) and the target's horizontal speed component are resolved into two components in and across the LOS (*Yo* and *Yt, Xo* and *Xt* respectively) or:

$$dRh = Yo + Yt = So \cos Br + Sh \cos A.$$
$$RdBs = Xo + Xt = So \sin Br + Sh \sin A.$$

The *algebraic* sign of the components can best be determined by inspection of a diagram of any particular problem. A component that tends to increase the basic coordinate is considered positive.

As yet the solution for present rates is incomplete. Direct range rate is defined as the rate of change of range along the LOS. Horizontal range rate (*dRh*) is not the same as direct range rate (*dR*), since it is not measured along the LOS. The change of bearing has to be converted to an angular rate of change which may be applied directly to initial bearing. A solution for elevation rate (*RdE*) must be developed, and it must also be converted to an angular rate. The completion of the solution with applicable formulas follows:

Range rate. Both *dRh* and *dH* are in the vertical plane through the LOS and are inclined to it by *E* and (90° − *E*) respectively. By inspection of figure 24A1, it can be seen that direct range rate is made up by resolving *dRh* and *dH* with respect to the LOS, or,

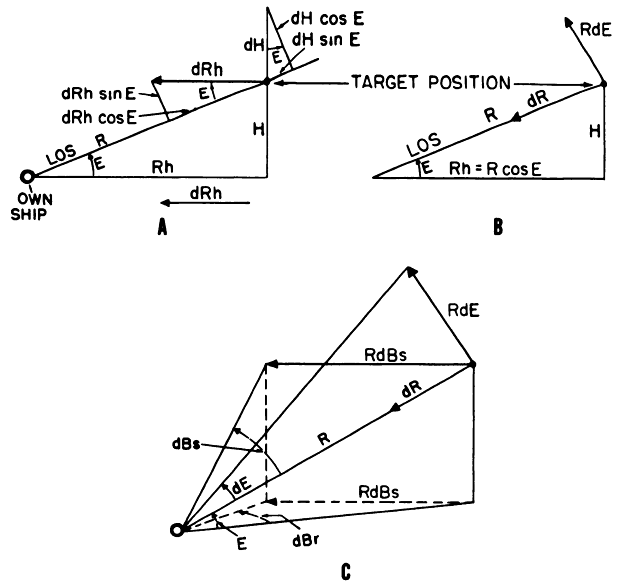


FIGURE 24A4.—Advance target position.

by referring to figure 24A4 (A and B), it can be seen where

$$dR = dH \sin E + dRh \cos E.$$

Converting a linear rate to an angular rate. The following formula may be used:

Angular rate (minutes of arc/sec) = linear rate (knots) × 2027/3600 (yd/sec) × 1000/*R* (yd) (to obtain angular rate in mils) × 3.44 (minutes of arc/mil).

Combining terms,
Angular rate (minutes of arc/sec) =

$$\frac{\text{Linear rate (knots)} \times 1936.}{R \text{ (yd)}}$$

Angular rate (mils/sec) =

$$\frac{\text{Linear rate (knots)} \times 563.}{R \text{ (yd)}}$$

Bearing rate. However, $dBs \times \Delta T$ cannot be combined directly with *jBr* to give *cBr*, since *dBs* is measured in the slant plane and *jBr* is measured in the horizontal plane. In order to convert *dBs* into an equivalent value in the horizontal plane (*dBr*) the linear rate must be divided by the horizontal component of *R*, which is *Rh*. See figure 24A1. It is evident that $Rh = R \cos E$. Then, referring to figure 24A4 (C):

$$dBr = \frac{RdBs \text{ (knots)} \times 1936}{R \text{ (yd)} \cos E} = \frac{RdBs \times 1936 \times \sec E.}{cR}$$

Elevation rate. Here again the linear rate (*RdE*) is computed first and then converted to an angular rate (*dE*). See figure 24A4 (A, B, and C).

$$RdE = dH \cos E + dRh \sin E.$$

$$dE = \frac{RdE \text{ (knots)} \times 1936.}{R \text{ (yd)}}$$

Now by multiplying the present rates by increments of time (ΔT) and combining the product with the quantities *jR*, *jBr*, and *jE* the equations for the generated target position mentioned above are obtained.

In a rangekeeper or computer it is more convenient to multiply by the reciprocal of the cosine (1/cos=sec) than to divide by the cosine itself. The Mark 1A computer was designed to use generated present range (*cR*) instead of observed present range, because at the time of design rangefinder ranges had to be used. Rangefinder ranging is necessarily intermittent. Continuous radar ranges of satisfactory quality are now available and are often introduced indirectly into the computing mechanisms by keeping the generated values equal to the observed.

24A5. Advance (predicted) target position

The present rates of relative target motion *dR*, *dBr*, and *dE* serve another purpose. Based on the assumption that these rates will remain constant for short periods of time, these present rates can be used to predict the target's position at the end of time of flight (*Tf*) of the projectile. The results may be considered as determining an *approximate line of fire.* As previously mentioned, this LOF, because of high speed of the target, may be considerably different from the LOS. Ballistic computations are based on this LOF.

B. Ballistic Computations

24B1. Statement of the problem

The LOF must further be corrected for the effects of gravity, drift, wind, loss of initial velocity (I.V.), non-standard atmospheric conditions, and certain geometric errors introduced by the fact that the motion of the gun is limited to train in the deck plane and to elevation in a plane perpendicular to the deck. The sum total of offsets from the LOS, based on these corrections, is known as sight angle (*Vs*) and sight deflection (*Ds*).

Surface range tables provide data for the point of

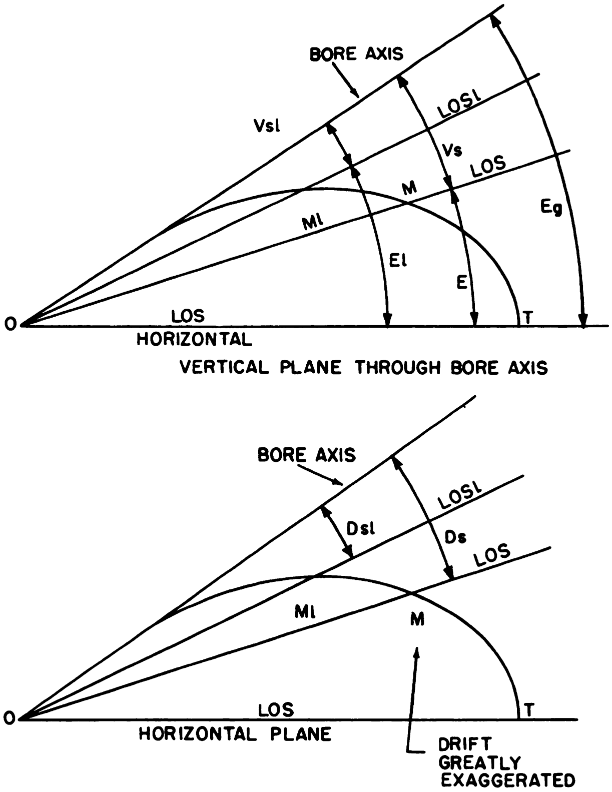


FIGURE 24B1.—Trajectory for an elevated target.

fall; that is the point at which the trajectory returns to the horizontal. This consideration is seldom of interest in AA fire, as the object is to produce a burst at some intermediate point of the trajectory to hit a target in the air. The trajectory *OMT* in figure 24B1 is the one that would be used against a surface target at T or an air target at M or M1 or any other point of the trajectory. No matter where the target is on OMT, the angle of departure, or vertical gun elevation (*Eg*) is the same. *However, sight angle* (*Vs*) *and sight deflection* (*Ds*) *will have different values for each point on the trajectory,* since these values are measured from the LOS, and the LOS is different for each elevated target position. OM is the LOS for a target at M, while OT is the LOS for a target at T. *Vs* and *Ds* depend upon both present range (*R*) and target elevation (*E*). Since corrections for wind and relative motion depend upon relative target bearing (*Br*), sight settings in any particular case also depend on *Br*. The problem is to determine values of *Vs* and *Ds* which will place the bore axis in the position which will produce the trajectory required to hit.

In the succeeding paragraphs it will be assumed that the trunnion axis is horizontal, and a closer examination will be made of the effects of: target motion, own-ship motion, complementary error, gravity, drift, wind, initial-velocity variations, and air density variations.

24B2. Prediction of relative target motion and advance target position

During time of flight the target moves from the position it occupied at the instant of firing. The gun must be fired, not at present target position, but at the advance position the target will occupy at the end of *Tf*. The LOS is directed at the present position, so the gun must lead the LOS and the target, by corrections in elevation and deflection.

Relative target motion has been described by the linear rates *dR, RdE,* and *RdBs*. Prediction for relative target motion, then, may be expressed by the equations:

Rt (the predicted change of range during Tf) $= dR \times Tf$.

Vt (the predicted angular change in minutes of arc in elevation during Tf) $= Tf/R2 \times RdE \times 1936$.

Dt (the predicted angular change in mils in bearing during Tf) $= Tf/R2 \times RdBs \times 563$.

In paragraph 24A4, the relationships between *RdE* and *dE; RdBs, dBs,* and *dBr* were shown. However, figure 24A4 (C), was slightly misrepresented in order to clarify the picture of these relationships to the solution. Actually, *dR, RdE,* and *RdBs* have no terminus until combined with a definite "time" such as *Tf*. See figure 24B2 (A and B).

From the above, it is seen that the angular quanti-

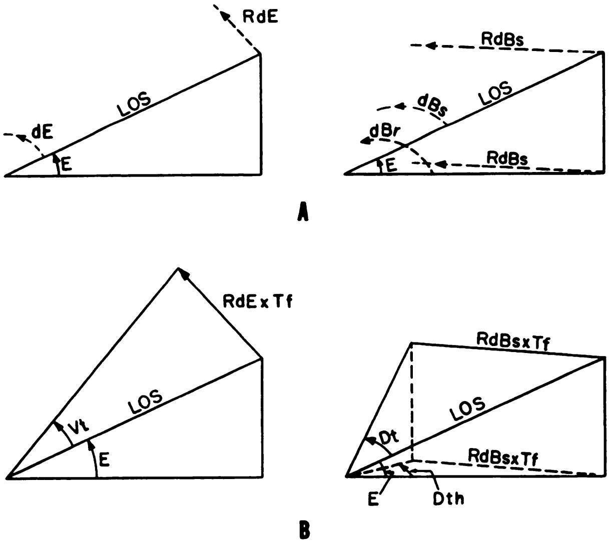


FIGURE 24B2.—Predictions for relative target motion.

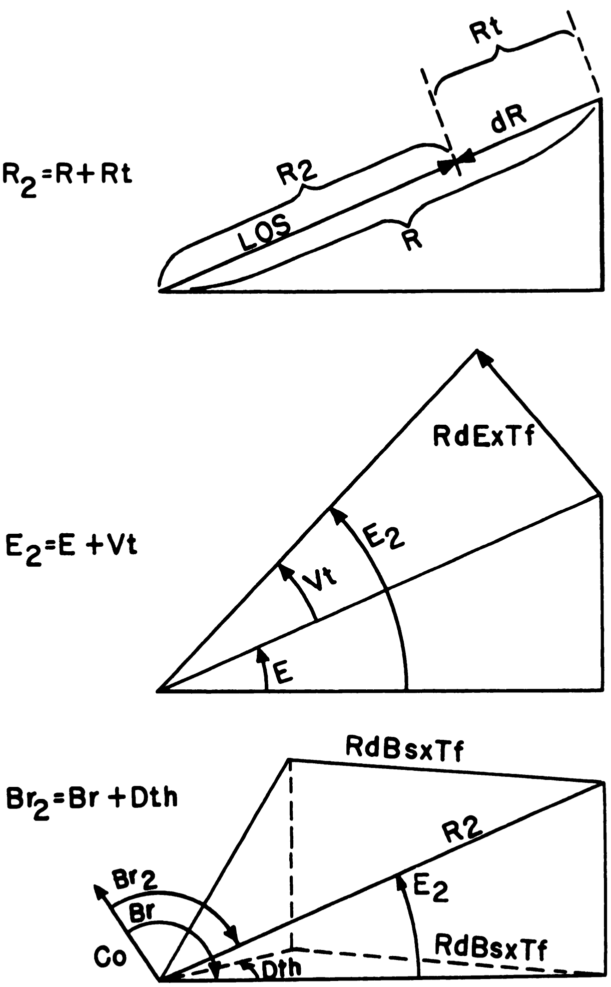


FIGURE 24B3.—How predicted values are obtained.

ties, dE, dBs, and dBr, are angles subtended by RdE and $RdBs$ at any instant. By multiplying RdE and $RdBs$ by Tf, the angles Vt, Dt, and Dth are formed. See figure 24B2(B). The similarity between the angles dBs and Dt, dBr and Dth, and dE and Vt, should not be confusing if it is kept in mind that they are equal for any given Tf.

The predicted position of the target in relation to own ship is defined by the three coordinates:

1. Advance (or predicted) range $R2$.
2. Predicted relative target bearing $Br2$.
3. Predicted target elevation $E2$.

Note the numeral 2 is used to indicate predicted values describing the advance position. Approximate values for $R2$ and $E2$ are obtained by these equations:

$$R2=R+Rt.$$
$$E2=E+Vt.$$

The expression for deflection prediction $Dt=Tf/R2$ x $RdBs$ is measured in the slant plane. The value for predicted relative bearing must be measured in the horizontal. Therefore, Tf x $RdBs$ is divided by horizontal range, $R_2 \cos E_2$, giving Dth. Consequently:

$$Br2=Br+\frac{RdBs \text{ x } Tf}{R2 \cos E_2}=Br+Dth.$$

24B3. Effect of deflection and elevation predictions on advance range

In the above equation, Rt does not take into account the fact that corrections for deflection and elevation have an effect on advance range; nor is the effect of a deflection setting on elevation shown in the expression for Vt.

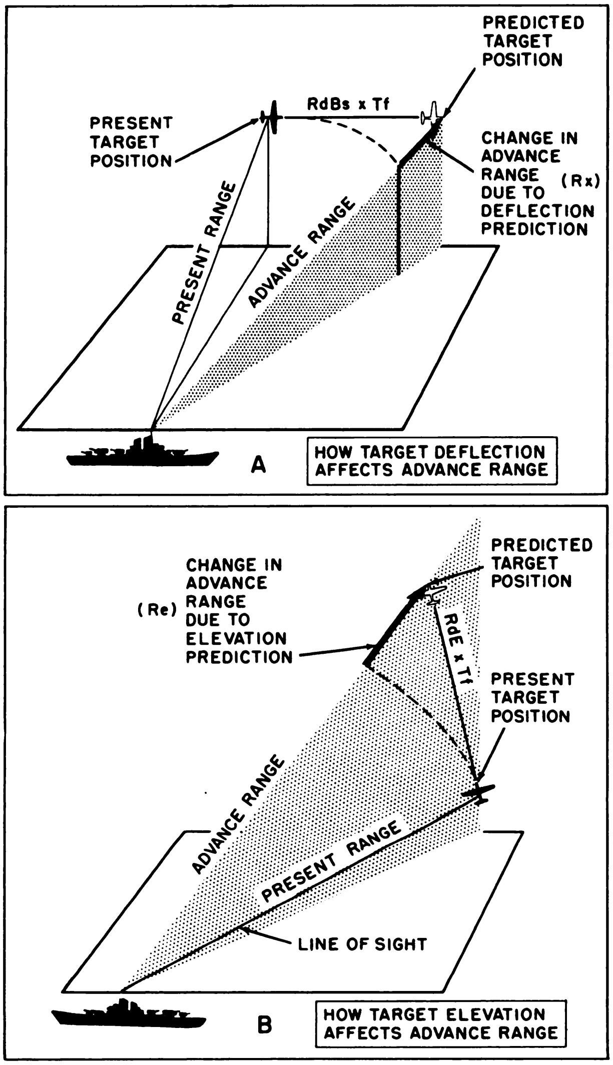

PREDICTED TARGET POSITION
RdBs x Tf
PRESENT TARGET POSITION
CHANGE IN ADVANCE RANGE (Rx) DUE TO DEFLECTION PREDICTION
PRESENT RANGE
ADVANCE RANGE
A
HOW TARGET DEFLECTION AFFECTS ADVANCE RANGE
CHANGE IN ADVANCE (Re) RANGE DUE TO ELEVATION PREDICTION
PREDICTED TARGET POSITION
RdE x Tf
PRESENT TARGET POSITION
ADVANCE RANGE
PRESENT RANGE
LINE OF SIGHT
B
HOW TARGET ELEVATION AFFECTS ADVANCE RANGE

FIGURE 24B4.—Effects of deflection and elevation on advance range.

Figure 24B4(A) shows the effect of deflection on advance range. With target angle 90° and the range rate 0, the predicted range would lie on the dotted circle instead of at the desired point on the straight line. The range correction due to deflection setting is shown by the heavy arrow, and is labeled *Rx*.

Figure 24B4(B) shows an additional but similar correction required in the AA problem. Here, for simplicity, a target is climbing perpendicular to the LOS, which gives $dR=0$ and $Rt=0$. The target again follows a straight course, so the error is the difference between the straight line and the circle, again shown by a heavy arrow and labeled *Re*. This is the range correction due to an elevation setting.

Although the angle made by the target and the LOS in both instances was taken as 90°, it should be evident that the two effects described will be present no matter what the target angle may be.

Figure 24B5 shows another error of size large enough to need correction in the AA problem. It is called *complementary error* and is the change in elevation caused by the deflection prediction (*Dt*). Assume the target, T, is at the elevation 45° and is flying on a straight course at right angles to the LOS along XY. The figure shows that if a train correction only were made to compensate for target deflection the predicted LOS (GC in the figure) would not run to the target, but would pass above it. The deflection of the target has made necessary a smaller angle of elevation. This change in elevation is complementary error (V*x*), and occurs because the gun's roller path is in the deck plane, and, as the gun is trained, its bore axis follows the path of a cone. *Vx* is *always* a *negative* correction.

24B4. Correction for effect of gravity

As in the surface problem, it is clear that the gun cannot be pointed directly at the advance target position, because the pull of gravity on the projectile during the time of flight will cause the trajectory to curve downward. The correction for gravity effect in the air problem is called superelevation (*Vf*). The angle the gun must be elevated to compensate for the effect of gravity depends on three factors: range, initial velocity, and target elevation. Superelevation varies inversely with I. V., because an increase of I. V. decreases the *Tf* for a given range, and gravity has less time to act. Superelevation increases with range, because range and time of flight are closely related. Superelevation varies as the cosine of the angle of elevation, decreasing as the gun is elevated. See figure 24B6. For a gun of given I. V., superelevation is considered to be a function of target elevation and range. In a computer, *Vf* is computed by a cam.

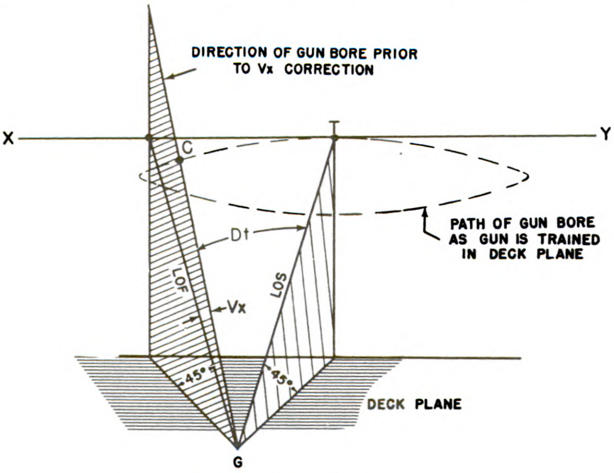

DIRECTION OF GUN BORE PRIOR TO Vx CORRECTION
X
Y
C
Dt
LOF
Vx
LOS
45°
45°
PATH OF GUN BORE AS GUN IS TRAINED IN DECK PLANE
DECK PLANE
G

FIGURE 24B5.—Complementary error.

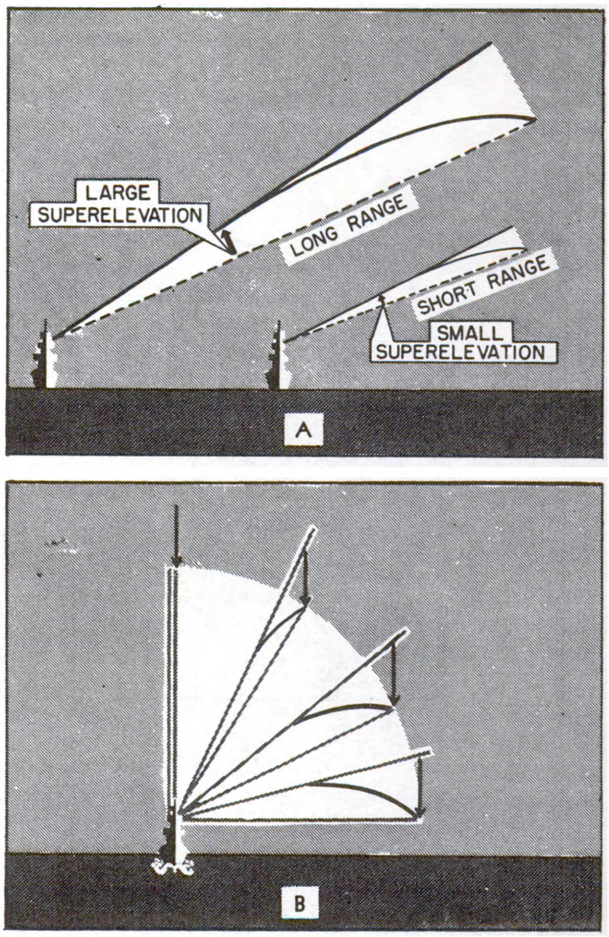


FIGURE 24B6.—A. Superelevation increases with range. B. Superelevation varies with the cosine of the angle of elevation.

24B5. Drift

The correction for drift measured in the slant plane through the predicted target position (*Dfs*) varies from point to point along the trajectory and must be computed for this predicted position of the target. Suitable curves, having drift, time of flight, and predicted target elevation as arguments are available. From these, the proper value of *Dfs* for a given problem may be obtained and a suitable drift cam may be cut for furnishing the proper value in a computer. Drift correction (*Dfs*) is always a minus quantity.

24B6. Wind

Figure 24B7 is a diagram of the computation of wind correction in the air problem. As in the surface problem, only horizontal wind is considered, and its value is based upon ballistic wind data obtained by aerological observations. However, because of the large probable difference between the LOS and LOF, wind correction is computed with respect to the LOF. Since own-ship motion has been considered as equivalent target motion in obtaining relative motion, apparent wind must be used in making wind corrections. The following definitions and symbols are essential to the computation and understanding of figure 24B7.

Cwg Predicted wind angle. The horizontal angle between the direction toward which the true wind is blowing

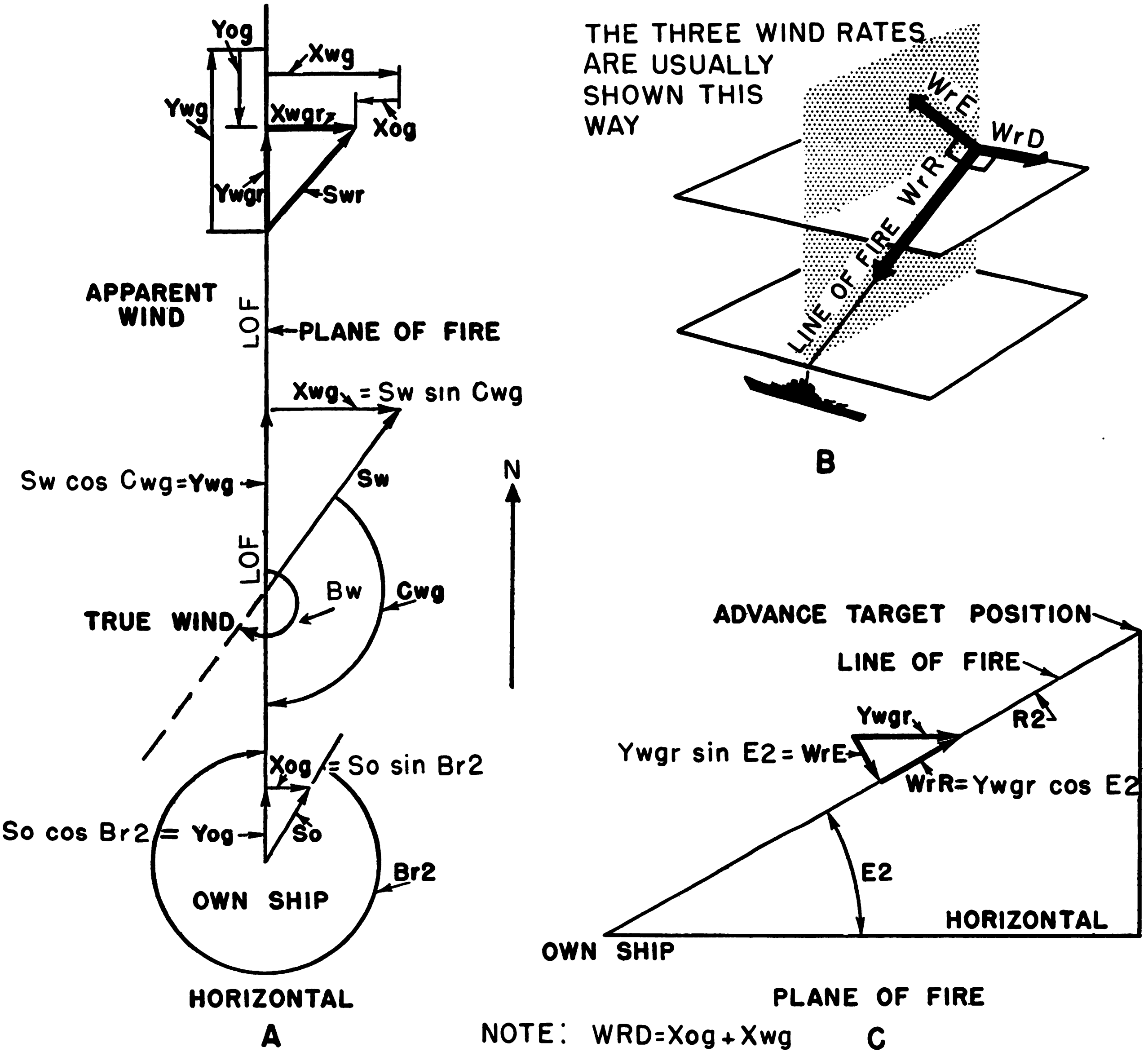


FIGURE 24B7.—Wind components.

	and the plane of fire, measured clockwise from the direction toward which the wind is blowing to that part of the plane of fire between the wind and own-ship vectors.
Xog	Cross component of own-ship velocity. The horizontal component of own-ship velocity perpendicular to the plane of fire. $Xog = So \sin Br2$.
Xwg	Cross wind. The horizontal component of true wind perpendicular to the plane of fire. $Xwg = Sw \sin Cwg$.
Xwgr	Apparent cross wind. The horizontal component of apparent wind perpendicular to the plane of fire. $Xwgr = Xog + Xwg$.
Yog	Line component of own-ship velocity. The horizontal component of own-ship velocity in the plane of fire. $Yog = So \cos Br2$.
Ywg	Range wind. The horizontal component of true wind in the plane of fire. $Ywg = Sw \cos Cwg$.
Ywgr	Apparent range wind. The horizontal component of apparent wind in the plane of fire. $Ywgr = Yog + Ywg$.
Bw	The compass direction from which the wind is blowing.
WrD	Linear component of apparent wind across the line of fire causing a deflection error.
WrR	Linear component of apparent wind in the line of fire causing a range error.
WrE	Linear component of apparent wind in the plane of fire and perpendicular to the line of fire causing an elevation error.
Dw	Wind deflection correction. The lateral deflection angle to correct for apparent cross wind. *Dw* (in mils) $= WrD \times Tf/R2 \times 563$.
Rw	Range wind correction. The correction in range for the effect of apparent wind. $Rw = WrR \times Tf$.
Vw	Wind elevation correction. The correction to elevation for the effect of apparent wind in the plane of fire. *Vw* (in minutes of arc) $= WrE \times Tf/R2 \times 1936$.

The components in and across the plane of fire are *Yog and Xog* for own ship, and *Ywg* and *Xwg* for true wind, as shown in figure 24B7. The algebraic sums of the components of *own ship's motion reversed* and *true wind* are the *components of apparent wind Ywgr* and *Xwgr* with respect to the plane of fire. Inspection of the direction of the component vectors with respect to the LOF will yield the proper algebraic sign to use when the errors caused by *Ywgr* and *Xwgr* are computed.

Apparent range wind *Ywgr* has components *WrR* and *WrE* in and perpendicular to the LOF. One effect of *WrR* is to alter time of flight. As *WrR* opposes projectile motion, *Tf* is increased. *Tf* must be corrected for range wind. Another effect of *WrR* is to alter the range attained by the projectile when fired at a given angle of departure. A range wind corrects in *Rw* will correct for this error. It is evident that to obtain a given range with *WrR* acting against the projectile a greater angle of elevation and a greater time of flight are required.

The component *WrE* will also influence the trajectory. If the target is at high elevation and the wind is blowing against the projectile toward the gun, *WrE* will tend to elevate the trajectory. A correction to gun elevation called, *Vw,* wind elevation correction, must be applied to counteract the error caused by *WrE.*

The apparent wind cross component, *WrD,* causes deflection of the projectile. Wind deflection correction, *Dw,* is applied to sight deflection to compensate for this effect.

24B7. Corrections for I. V. variations

Not all projectiles can be fired at the designed initial velocity, because of gun erosion and changes in temperature of powder charges. An altered I. V. will change the trajectory, in that a projectile fired below designed I. V. will travel more slowly and will drop sooner than a projectile fired at or above designed I. V. Two corrections are necessary, *Rm,* range correction for I. V. variations, and *Vfm,* elevation correction for I. V. variations. *Rm* is a function of I. V. variation and time of flight. *Vfm* is a function of I. V. variation, *R*2 and *E*2.

24B8. Correction for air density variation

Air density higher than standard would result in a projectile's falling short of a desired range; or, in contrast, an air density lower than standard would result in a projectile's going beyond, (over) a target at the specified range. Then, to have a projectile reach a desired range when air density is higher than standard, and to counteract the resulting increase in time of flight, a more elevated trajectory would be required. The elevation correction, *Vu,* is a function of the percent of variation from standard air density; and is a function of *R*2 and *E*2.

Practically, this correction does not exist in the mechanical solution of the AA problem. It is computed from a range table or nomogram and is either entered as a spot or converted to I. V. variation.

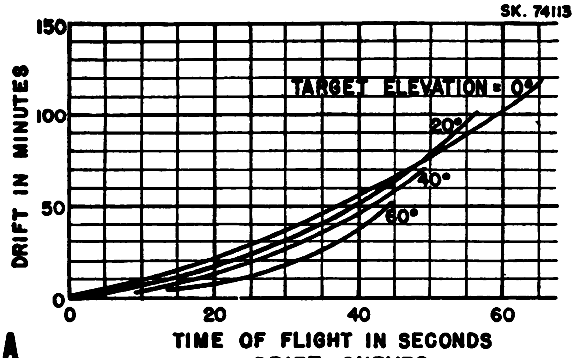
24B9. Ballistic data

A trajectory graph appended to OP 551, 2nd rev., shows the trajectories of the 5″/38 gun when fired at various angles of departure under standard conditions. Any variation from these conditions results in modifications of the trajectory. While it would be possible to make a similar graph for any other particular set of conditions, it is obviously impracticable to do so for a wide variety of sets of conditions. Instead, the graph as shown serves as the basis for many of the

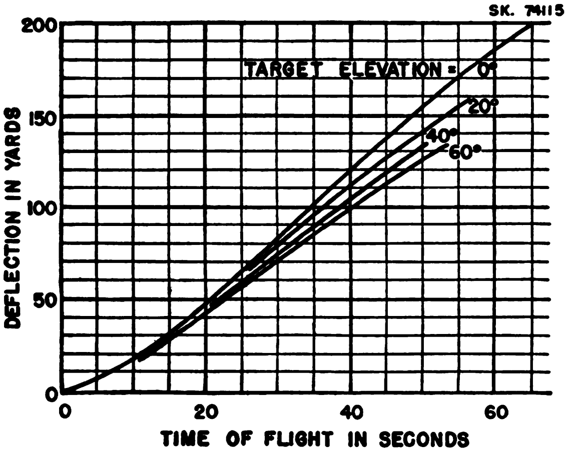
BALLISTIC DATA — 5"/38 CALIBER GUN

FOR 54 LB. AA COMMON PROJECTILE, I.V. 2600 F.S.

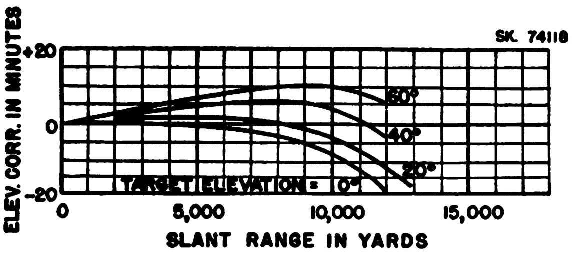
ABRIDGED FROM INDICATED BUREAU OF ORDNANCE SKETCHES



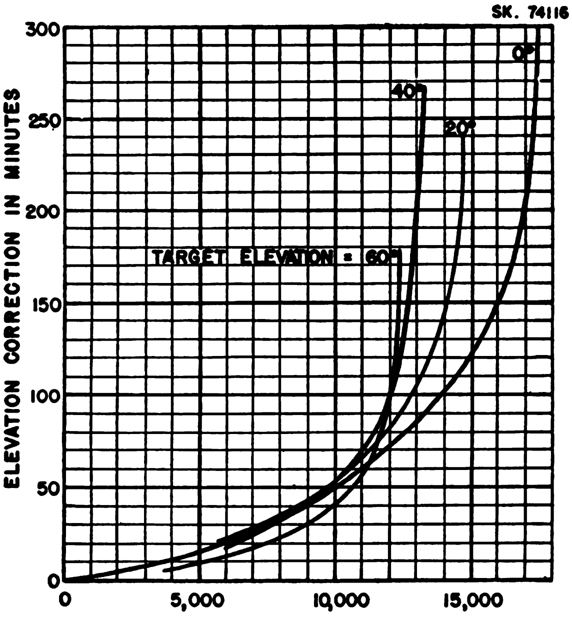
A DRIFT CURVES



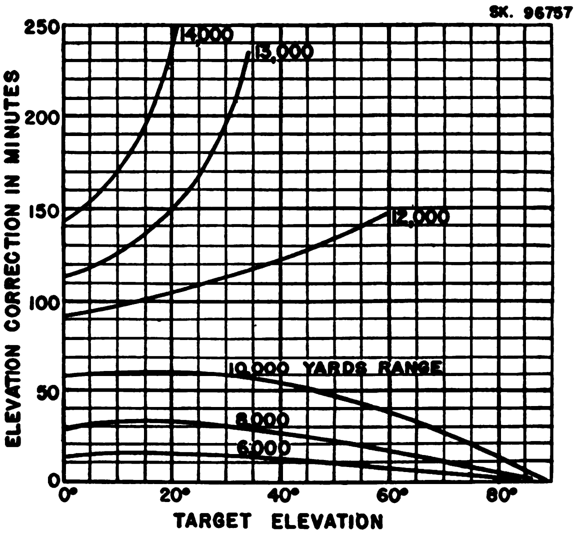
B 10 KT. CROSS-WIND EFFECT



C 10 KT. REAR RANGE-WIND ELEVATION CORRECTIONS



D 100 F.S. I.V. LOSS ELEVATION CORRECTIONS



E 10% AIR-DENSITY VARIATION ELEVATION CORRECTIONS

Figure 24B8.—Typical graphs of ballistic data.

ballistics which correct for variations. Among items directly available from this graph for any point on a given trajectory are:

1. *Time of flight* and *fuze setting.*
2. *Height.* Read from the vertical scale at the left edge of the drawing.
3. *Horizontal range.* Read from the range scale at the bottom.
4. *Slant range.* Obtained by using dividers and the horizontal range scale.
5. *Target elevation* (position angle). Measured by laying straight edge through origin and point on trajectory, and reading angle of position scale.
6. *Superelevation.* Angle at which gun must be elevated above predicted target position to allow for trajectory curvature in the vertical plane caused by gravity.

Some corrections for variations from standard conditions are provided on graphs, generally about 18 inches by 24 inches in size, issued by the Bureau of Ordnance. To acquaint the student with the type of information available, excerpts from some of the graphs for the 5″/38 gun are reproduced in miniature in figure 24B8.

C. Gun Positioning

24C1. Summary of sight deflection and sight angle

Any error in gun positioning not accounted for by the preceding discussion can, in theory, be accounted for by the application of a deflection spot (Dj) and an elevation spot (Vj) of suitable size.

$Ds = Dt + Dw + Dj - Dfs$, where:

Dt is deflection prediction,
Dw is wind deflection correction,
Dj is deflection spot,
Dfs is drift correction.

$Vs = Vt + Vw + Vj + Vfm + Vf + Vu - Vx$, where:

Vt is elevation prediction,
Vw is wind elevation correction,
Vj is elevation spot,
Vfm is I. V. elevation correction,
Vu is air density correction,
Vf is superelevation,
Vx is complementary error.

Also, $R2$, which enters into the determination of the ballistics listed above, may be expressed as:

$R2 = cR + Rt + Rw + Rj + Rm + Rx + Re$, where:

cR is generated present range,
Rt is range prediction,
Rw is range wind correction,
Rj is range spot,
Rm is I. V. range correction,
Rx is change in advance range due to deflection,
Re is change in advance range due to elevation.

24C2. Makeup of gun orders

Under normal conditions, the deck is not horizontal and guns are positioned by gun orders made up in a computer. These gun orders are based on the director LOS; they include Vs and Ds, which must continuously be corrected for inclination of the deck. This correction is known as *trunnion tilt correction.* Since the gun's motion is limited to train in the deck plane and to elevation in a plane perpendicular to the deck, gun orders must be computed in those planes and must be based on the standard reference of the ship. Trunnion tilt corrections assume greater importance in AA fire than in surface fire, because of higher gun elevation. These corrections are not included in Vs and Ds, because of the rapidity with which they change, but are computed and included in gun train and gun elevation order.

Accordingly, gun elevation order $E'g$ contains (1) the elevation of the director LOS above the deck plane Eb, (2) the vertical offset Vs to account for prediction and ballistics, and (3) the trunnion tilt correction in elevation Vz or,

$$E'g = Eb + Vs - Vz = E + L + Vs - Vz.$$

Gun train order is made up of (1) director train $B'r$, (2) the lateral offset Ds to account for prediction and ballistics, and (3) trunnion tilt correction Dz. Actually Ds is in the slant plane and must be projected into the deck plane as jDd to be made usable for the gun or,

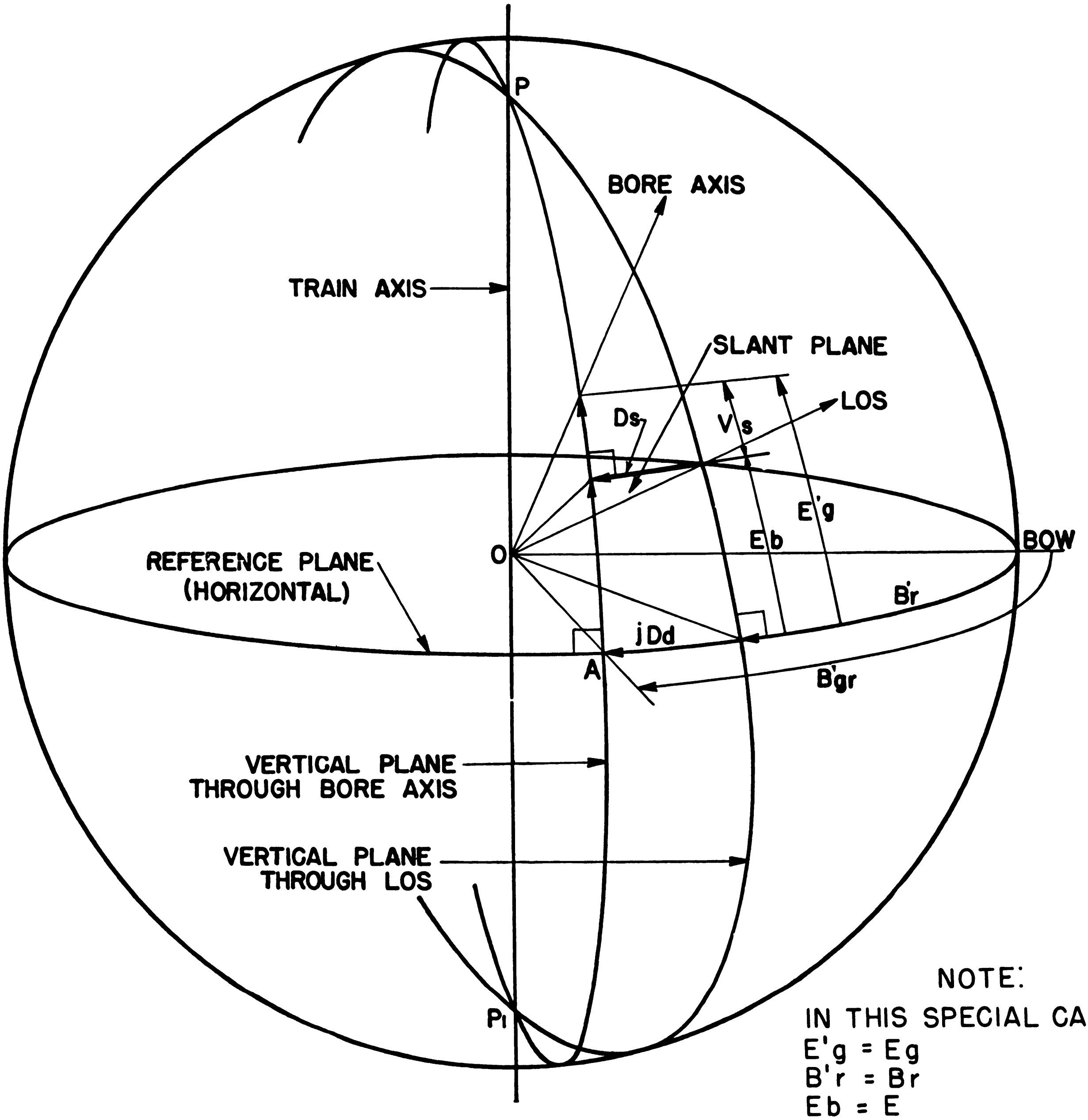
$$B'gr = B'r + jDd + Dz = B'r + Dd.$$

These quantities can be seen in figure 24C1 for a horizontal deck, and figure 24C2 for an inclined deck.

To provide continuous corrections to gun orders for deck inclination, the dual-purpose system uses a stable element to measure and transmit level and crosslevel. While similar to the stable vertical used in surface systems, the stable element incorporates one important difference. In the stable vertical the level gimbal is the outer one, and its axis is fixed in relation to the deck. Level, L', is measured in a plane perpendicular to the deck plane, about an axis in the deck plane. As the crosslevel gimbal axis is kept parallel to the horizontal, the value of crosslevel, Zh, is measured about a horizontal axis.

In the stable element, however, the two gimbals are reversed. The crosslevel gimbal is the outer one, and its axis is fixed with respect to the deck. This results in the measurement of crosslevel, *Zd,* about an axis in the deck plane. Since the level gimbal is kept in the horizontal, level, *L′,* is measured in the vertical plane, about an axis in the horizontal. Figure 24C3 shows the difference in the ways the quantities are measured.

This difference in design is made necessary by the difference in design of the director sights. In the main-battery system the sights are not stabilized, and



NOTE:
IN THIS SPECIAL CASE
$E'g = Eg$
$B'r = Br$
$Eb = E$
Dz and $Vz = 0$
$jDd = Dd$

FIGURE 24C1.—Gun orders, deck horizontal.

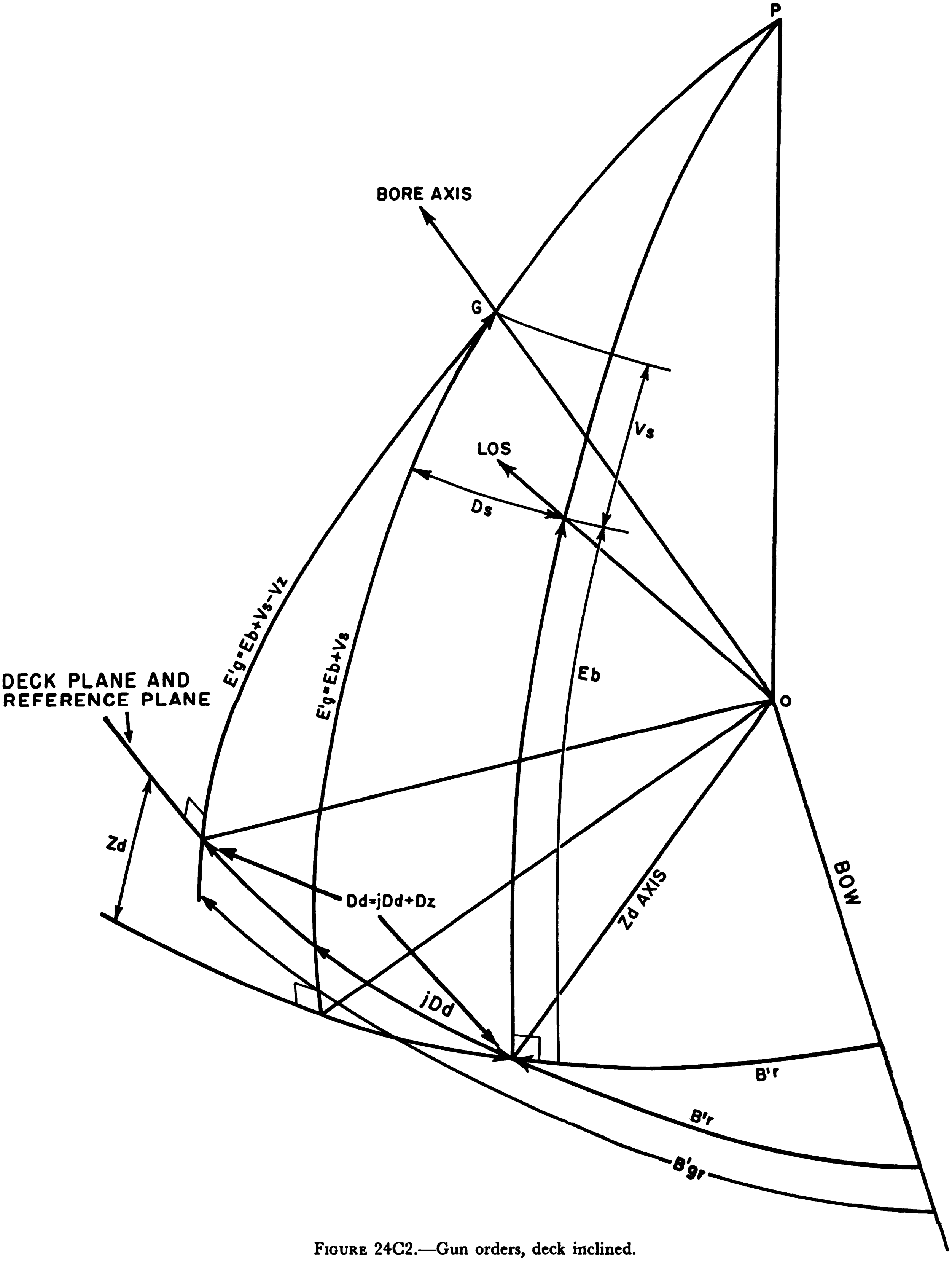
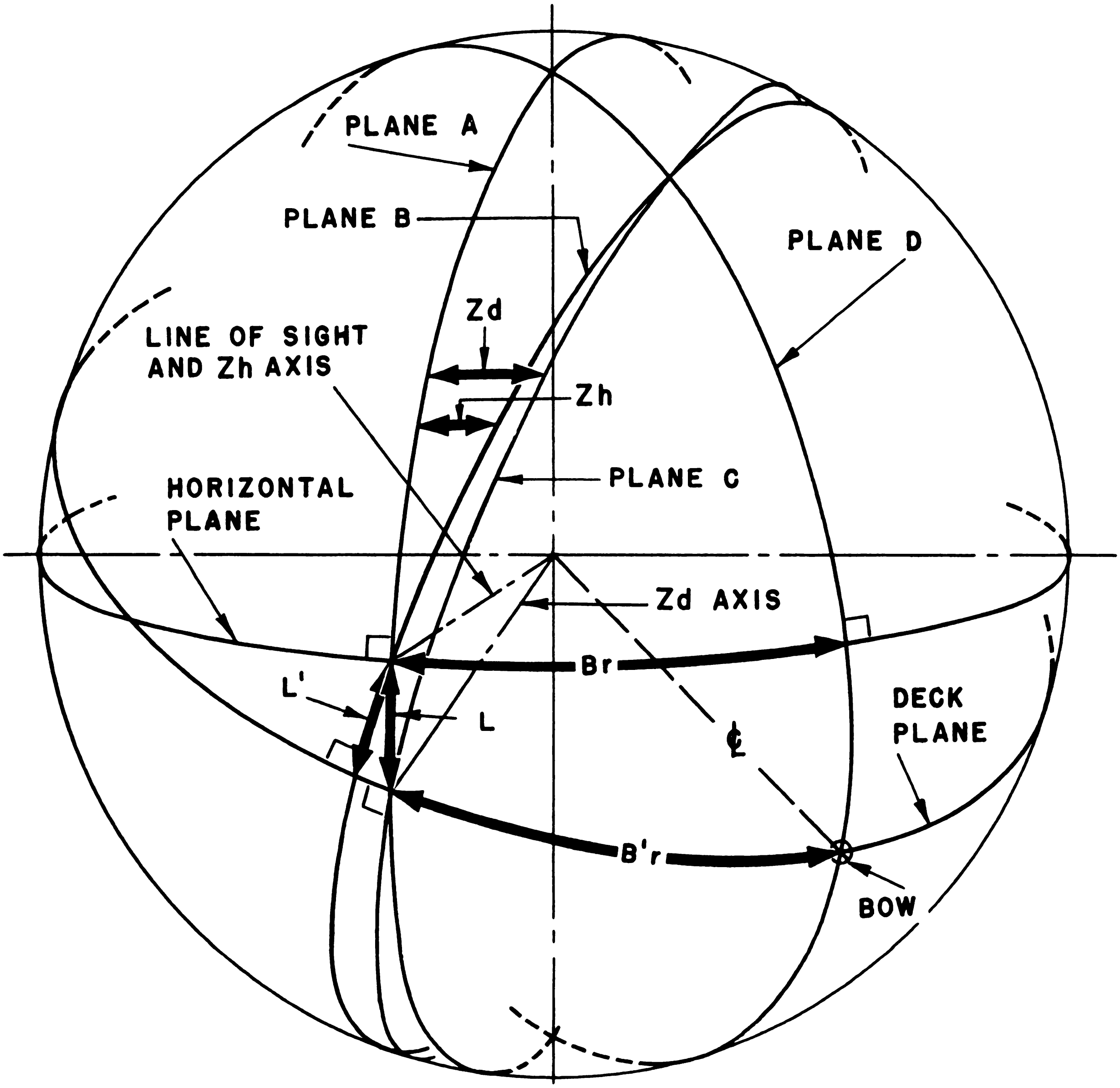


FIGURE 24C2.—Gun orders, deck inclined.



PLANE A - VERTICAL PLANE CONTAINING LINE OF SIGHT

PLANE B - PLANE PERPENDICULAR TO DECK PLANE CONTAINING LINE OF SIGHT

PLANE C - PLANE PERPENDICULAR TO DECK PLANE AT INTERSECTION OF PLANE A AND DECK PLANE

PLANE D - VERTICAL PLANE THROUGH CENTERLINE OF SHIP

Figure 24C3.—Comparison of methods of measuring level and crosslevel.

elevation is measured in a plane perpendicular to the deck. In the dual-purpose system, director sights are stabilized as shown in figure 25B6, *so that the sighting plane is kept vertical and elevation and level are measured in the vertical plane.* Stabilization is necessary because the use of an elevated LOS would introduce large errors if an unstabilized sight were employed. Extensive study of the stable element will be made later.

24C3. Fuze settings

Since the results of the computations of Vs and Ds are, at best, close approximations, AA fire normally uses fuzed projectiles calculated to burst in the vicinity of the target and destroy the target by fragmentation. Time-fuzed projectiles require the calculation of fuze time (F). When VT fuzes are used, the same calculations are necessary, as time-fuzed projectiles are interspersed with VT-fuzed projectiles to ensure some bursts, as an aid to improving an inaccurate solution; and in addition mechanical time fuzes are still used with star shells.

If a mechanical fuze could be set and fired at the same instant, a fuze setting equivalent to Tf for the advance position of the target would cause the projectile to burst at the proper time. Actually the fuze is set before the projectile is loaded. The time elapsed between setting the fuze and firing the projectile is called dead time (Tg). Its value, determined by analysis of drills and firings, is usually about 4 seconds. In order to set the fuze Tg seconds before firing and still obtain a burst at the target, it is necessary to predict the value of Tf that will exist when the projectile is fired.

This fuze setting is determined indirectly in the practical solution. To be accurate, both the change in predicted target elevation and the change in advance range during dead time should be accounted for. The change in predicted target elevation is small enough to be neglected. However, change in range is corrected for and may be considered to be $Tg \times dR$. This value, combined with $R2$, gives $R3$, fuze range. Since dR is normally negative, this means that $R3$ is usually smaller than $R2$. Fuze setting F is based on $R3$. If, after firing, the time-fuzed projectile is observed to burst behind or ahead of the target, a correction must be applied to F. This normally is accomplished by a range spot, Rj.

$$R3 = R2 - (Tg \times dR).$$

The fuze setting is the time of flight corresponding to $R3$.

Chapter 25

LINEAR-RATE ANTIAIRCRAFT FIRE CONTROL SYSTEMS

A. General Description

25A1. Introduction

Antiaircraft fire control systems of various types are designed to control guns ranging in size from light machine guns through 8″/55 rapid-fire guns. For convenience, these systems will be considered in two classes: those which determine rates of change of relative target motion as linear rates (linear-rate systems), and those which measure the angular velocity of the line of sight by gyroscopic means (relative-rate systems, described in chapter 26).

The Gun Fire Control System Mark 37 is the most significant example of the linear-rate system. It is installed on destroyers, cruisers, carriers, battleships, and some types of large auxiliaries. It is the primary means of control of the 5″/38, 5″/54, and 6″/47 guns for both surface and antiaircraft fire; it may be used, with appropriate cross connections, to control heavy machine-gun mounts, or major-caliber surface-type guns in special uses. The Computer Mark 1A, which normally is a component of the Mark 37 system, is also used as a part of the Gun Fire Control System Mark 54 for the control of 8″/55 guns on cruisers of the *Salem* class.

The discussion in this chapter, unless otherwise stated, is limited to the modifications of the system designed to control the 5″/38 gun. For details of other modifications, as well as for specific instructions regarding adjustments, repairs, tests, and the like, the student is referred to appropriate publications of the Bureau of Ordnance, while appropriate OpNav and Fleet training publications must be consulted for operational doctrine.

25A2. Principles

The Gun Fire Control System Mark 37 is similar in many respects to the main-battery systems described in chapter 20. All elements of the systems are referred to a common reference system, with mechanical provisions for correcting the solution for the effects of roller-path inclination and parallax. Inclination of the deck plane from the horizontal is measured and compensated for by a gyroscopic stable element.

The director system measures target position in three coordinates: range, relative target bearing, and target elevation. Fundamental geometric relations are shown in figure 25A1.

The primary functions of the system are to provide:

1. Continuous automatic gun positioning.
2. Continuous automatic fuze setting.
3. Continuous sight-angle and sight-deflection indication at the guns.
4. Continuous-aim, selected-level, and selected-crosslevel fire.
5. Star-shell fire control.

25A3. Component units

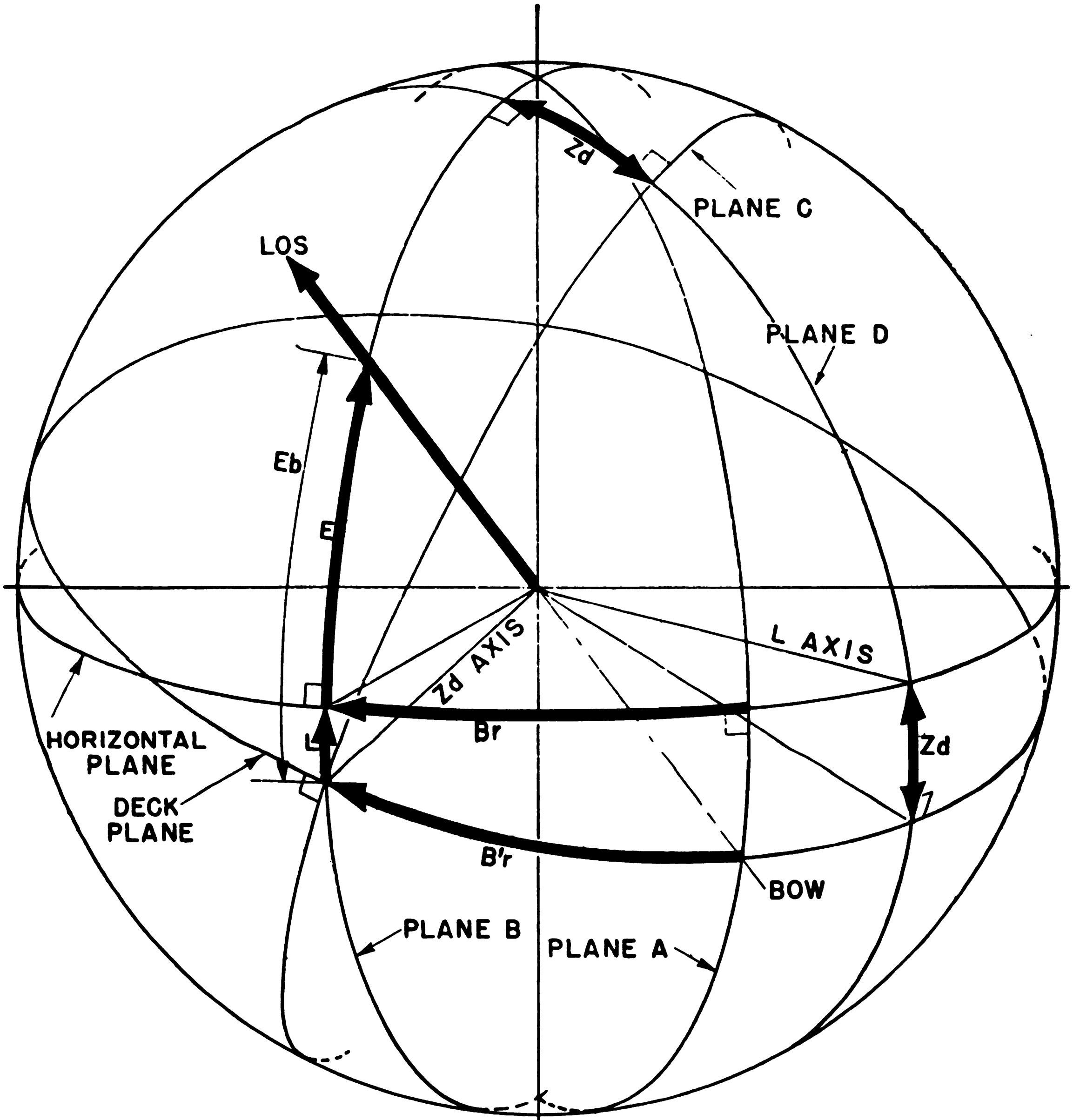
A complete system consists of three major units: a Mark 37 director, with a radar, a Mark 6 stable element, and a Mark 1A computer, with the associated instruments at the gun.

Destroyers and large auxiliaries carry one complete system. See figure 25A2. Cruisers and carriers have two systems, while battleships have four.

Directors are installed high in the ship's structure, while stable elements and computers are installed below decks in protected plotting rooms. All elements are connected by a synchro transmission system, and are tied into this transmission system at one or more switchboards located in the plotting rooms.

Some battleships have two separate plotting rooms, each containing two computers and two stable elements. Some large carriers have two plotting rooms, each with one computer/stable-element installation. Cruisers and the other carriers have one AA plotting room with two such installations. All other ships equipped with a Mark 37 system have one plotting room, with one computer and one stable element.

Normally, each director in a multiple installation



A. VERTICAL PLANE THROUGH FORE-AND-AFT AXIS

B. VERTICAL PLANE THROUGH LINE OF SIGHT

C. PLANE PERPENDICULAR TO DECK THROUGH INTERSECTION OF DECK PLANE AND PLANE B

D. PLANE PERPENDICULAR TO PLANE B AND DECK PLANE

$$Br = B'r + jB'r$$

FIGURE 25A1.—Space relations in the antiaircraft problem.

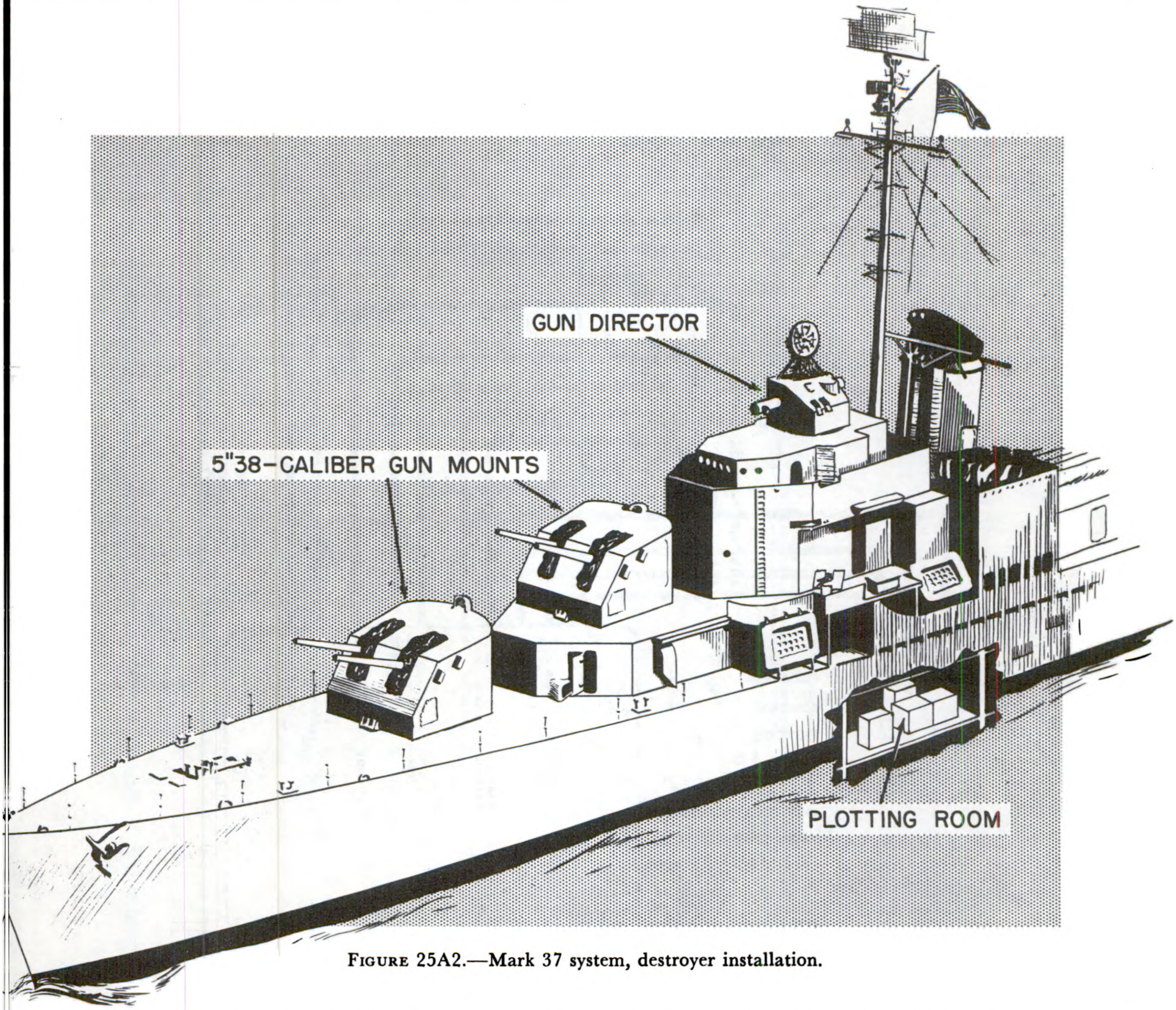


FIGURE 25A2.—Mark 37 system, destroyer installation.

controls a designated group of guns and is connected to a designated computer. However, switching arrangements permit any director to control any or all guns and to be connected to any one of the computers. Also, on many ships, the Mark 37 director can control part or all of the heavy machine-gun battery.

On cruisers and battleships, the Mark 37 director can supply director train and director elevation to the main-battery rangekeeper. In addition, the three major units of the Mark 37 system can control the main battery in AA fire, using pre-selected fuze settings.

25A4. Parallax and roller-path corrections

In order to obtain maximum flexibility, all train and elevation orders and measurements are based on a common reference system. Range errors due to horizontal distances between units of the system are not considered. However, roller-path inclination, horizontal parallax, and vertical parallax are accounted for.

Roller-path inclination. A roller-path tilt corrector or compensator to correct for roller-path inclination is installed at each gun. On ships with more than one director, each has a roller-path tilt corrector. When there is only one director, its roller path is the reference plane and it has no tilt corrector.

Horizontal parallax. The reference point in train is usually at the director, if there is only one; or, if more than one, then midway between the forward and after directors on their centerline. The computer transmits the value of parallax correction for a 100-yard horizontal base (*Ph*) to all guns and directors. In the

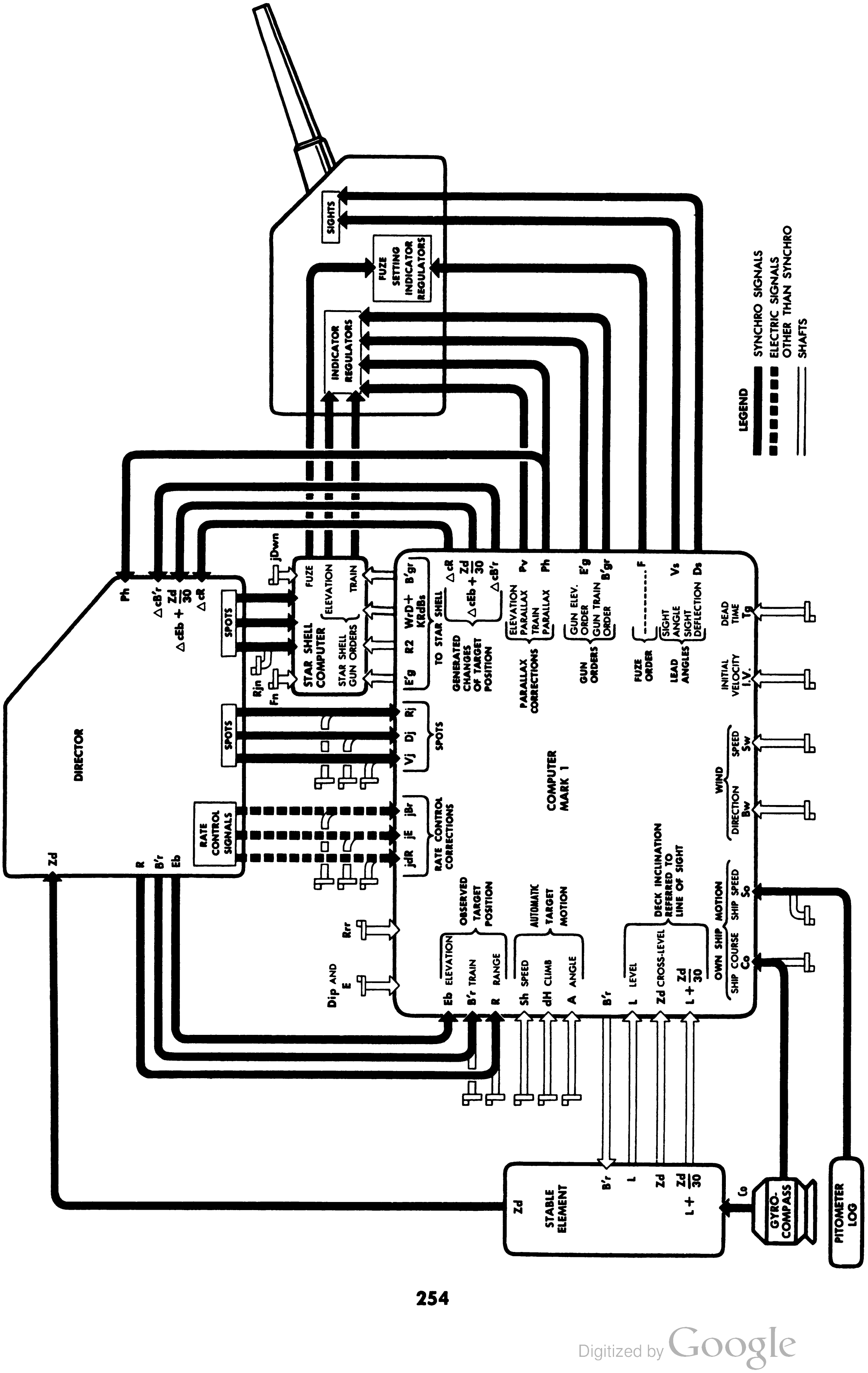


FIGURE 25A3.—Mark 37 system, diagram.

train indicator-regulator of each unit, this parallax correction for 100 yards base is converted (by a simple gear ratio) to correction for the unit's actual distance from the reference point. Where only one director is installed, the center of its roller path is taken as the reference point. In this situation, the director needs no parallax correction and has no parallax mechanism.

Vertical parallax. The base length or vertical parallax is the distance between the director telescopes and the mean gun-trunnion height. Individual trunnion-height variations from the mean are small enough to neglect. In multiple installations, telescope-height variations between directors are also neglected. A unit vertical base length, usually 30 feet, is used. Parallax (Pe) based on this 30-foot height is calculated in the computer and sent to the guns as part of gun elevation order. Hence, no special vertical parallax mechanism at the mounts is needed.

A special case exists on large carriers such as the *Essex* and the *Midway* classes. On these ships, horizontal distances are so great that a vertical parallax correction for horizontal base length (Pv) is necessary. This correction is calculated in the computer for a unit base length of 100 yards. The result is sent to the guns as a separate quantity. At each mount, a parallax unit in the elevation indicator-regulator converts the unit value of parallax to the proper amount for the actual base length. The resulting correction is applied to the gun elevation response.

25A5. Flow of information

Figure 25A3 is a schematic diagram showing the principal interconnections of a single Gun Fire Control System Mark 37. All electrical circuits between units of the system pass through the fire control switchboard.

The director, in addition to telescopes, carries a rangefinder and radar equipment. This equipment is used to measure and transmit to the computer: director elevation (Eb), director train ($B'r$), and present range (R). The control officer in the director may estimate target angle (A), target horizontal speed (Sh) and rate of climb (dH). When the computer is in the automatic method of rate control, it is not necessary to make these estimates. The control officer sends these values by telephone to the computer operators. Hand-operated transmitters in the director provide electrical transmission of elevation, deflection, and range spots to the computer.

The stable element, a unit very similar to the stable vertical studied in chapter 20, measures level angle (L) and crosslevel angle (Zd). These values are sent mechanically to the computer. A third value, $L+Zd/30$, which is explained fully in article 25B14, is also sent mechanically to the computer. Here it is added to $\triangle cE$, forming $\triangle cE+L+Zd/30$, which is transmitted electrically to the director. In the director, $\triangle cE+L+Zd/30$ is used to keep the line of sight automatically on the target in elevation. Crosslevel (Zd) is transmitted electrically from the stable element to the director to stabilize the optics and radar antennas in crosslevel.

Electrical inputs to the computer come from the director, the ship's gyro compass, and the pitometer log (speed). As explained above, inputs to the computer from the stable element are mechanical. Finally, the computer operators apply various manual inputs to the instruments. The quantities computed and transmitted electrically to the guns are:

1. Gun elevation order ($E'g$).
2. Gun train order ($B'gr$).
3. Sight angle (Vs).
4. Sight deflection (Ds).
5. Fuze-setting order (F).
6. Train parallax for a 100-yard horizontal base (Ph).
7. On large carriers, elevation parallax for a 100-yard horizontal base (Pv).

These values are used for gun positioning, sight setting, and fuze setting. Indicator-regulators at the mounts provide gun positioning and fuze setting either by fully automatic means or by matching pointers.

In addition, the computer generates and transmits to the director changes in range (ΔcR), elevation (ΔcE), and train ($\Delta cB'r$). With level (L) and crosslevel (Zd), these changes are used to hold the director optics and radar on the target continuously. This process includes keeping the rangefinder wander marks on the target and the radar notch under the target pip. This provision reduces the work of director personnel in keeping on target, and forms the basis for rate control.

25A6. Illumination control

Star shells can be fired by the dual-purpose guns to illuminate surface targets. A star-shell computer calculates gun train, elevation, and fuze-setting orders. This instrument is attached to the Mark 1A computer in the plotting room. It receives mechanically, from the Mark 1A computer, basic information upon which it bases its caluclations. In addition, the star-shell computer receives spots electrically from a star-shell spot transmitter located in the director. With this instrument, a Mark 37 system can control star-shell and surface fire simultaneously on the same target.

B. Director

25B1. General

The Mark 37 director is designed to control 5″/38, 5″/54, or 6″/47 dual-purpose guns against either air or surface targets, and to provide illumination control for star shells. It can be trained 375 degrees in either direction from its neutral or secured position. The limit in train is imposed by the amount of twist the director's connecting cables can safely stand. In elevation, mechanical limit stops restrict movement of the line of sight to +110 degrees and −25 degrees. The Mark 37 director has some 92 modifications, but the variations, with few exceptions, are minor. Only the more important variations will be discussed.

25B2. Primary functions

The primary function of the director is to determine target position, according to the three coordinates that determine the line of sight:

1. *Director train* ($B'r$). The angle between the fore-and-aft axis and the vertical plane containing the line of sight, measured in the deck plane, clockwise from the bow.
2. *Director elevation* (Eb). The elevation of the director's line of sight above the reference plane, measured in the vertical plane containing the line of sight. $Eb=E+L$.
3. *Present range* (R). The distance of the target from own ship, measured along the line of sight.

These quantities are used in the computer as:

1. The basis for gun train and elevation orders.
2. Part of the initial computer set-up.
3. A check on the accuracy of the solution generated by the computer.

25B3. Secondary functions

The director's secondary functions can be summarized by saying that it is the control station for the entire fire control system. When the system is functioning as designed, all units operate by remote control from the director. As long as the problem is being solved correctly, only the gun-loading crews have work to do. All other personnel merely stand by and observe, ready to step in to help when necessary. When changes in the problem set-up are necessary, the director crew can accomplish them by remote control. In order to control the entire system, the director is equipped to:

1. Make initial estimates of target angle, target horizontal speed, and rate of climb (used for manual rate control).
2. Spot service projectile fire and transmit these spots.
3. Spot star-shell fire and transmit these spots.
4. Control rate calculations in the computer by correcting settings of target angle, target horizontal speed, and rate of climb.

25B4. Inputs

All inputs to the director are received *via* synchro transmission systems. They are:

1. Bearings correction ($\Delta cB'r$).
2. Elevation correction ($\Delta cE+L+Zd/30$).
3. Range correction (ΔcR).
4. Crosslevel (Zd).
5. Train parallax for 100-yard horizontal base (Ph) (in multiple-director installations only).

25B5. Outputs

Normally, all outputs from the director are sent *via* synchro transmission systems. These outputs are:

1. Director train ($B'r$).
2. Director elevation (Eb).
3. Observed present range (R).
4. Range spot (Rj).
5. Deflection spot (Dj).
6. Elevation spot (Vj).
7. Rate control or *on target* signals for range, elevation, and bearing. Trainer's *on target* signal is also remote control key for starting computer time motor.
8. Star-shell range spot (Rjn).
9. Star-shell elevation spot ($E'jn$).
10. Star-shell deflection spot ($B'jn$).

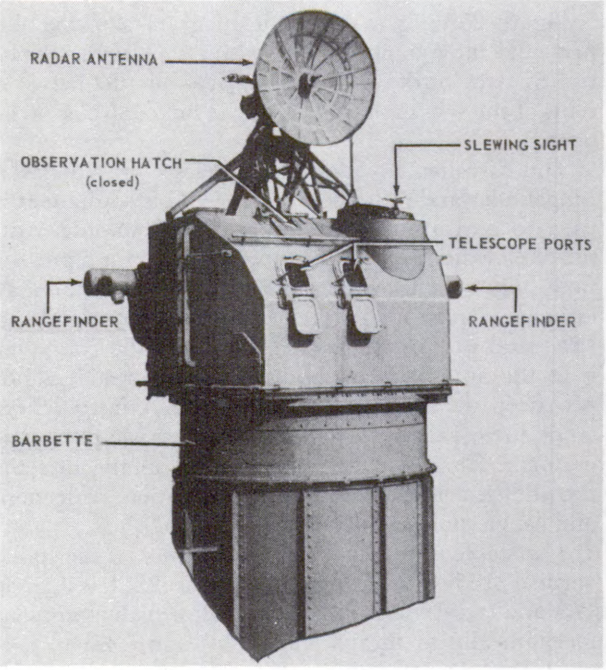


FIGURE 25B1.—Gun Director Mark 37.

25B6. Components of director

The external appearance of the director is shown in figure 25B1. The most important instruments are the two telescopes, the rangefinder, and the radar. These are essential to the primary functions of the director: measuring director train, director elevation, and present range.

The director is supported on a foundation built into the ship's structure. This foundation is so machined as to reduce roller-path tilt to a minimum. The principal supporting elements are the base ring, the carriage, and the shield. The shield is attached to the carriage, which is supported by roller bearings on the base ring. The base ring rests on the director foundation.

The personnel (six or seven men) enter the director through the foundation and base ring, passing through hatches in the floor of the carriage. The shield has one or two observation hatches in the top. There are two telescope ports in the front plate and a vertical slot in each side plate for the protruding ends of the rangefinder. Shield thickness varies between the thin, weather-protective type for destroyers, and the heavy, splinter-proof 1½-inch thick type on battleships. Telescope port covers are handwheel-operated, and on heavier shields so are the observation hatch covers. In most modifications of the director, the shield and carriage support the component parts listed below. Some of these parts are shown in figures 25B1 and 25B2:

1. Two Movable-Prism Telescopes Mark 60.
2. Slewing sight.
3. Stereoscopic Rangefinder, 15-foot Base, Mark 42, and its carriage.
4. Change-of-range receiver.
5. Crosslevel gear and power drive.
6. Training gear with both manual and power drive.
7. Elevating gear with both manual and power drive.
8. Director train receiver-regulator.
9. Director elevation receiver-regulator.
10. Director crosslevel receiver-regulator.
11. Spot transmitter (bearing and elevation).
12. Range-spot transmitter.
13. Star-shell spot transmitter.
14. Roller-path tilt corrector (in multiple installations).
15. Horizontal-parallax mechanism (in multiple installations).
16. Radar antennas, control equipment, and indicators.
17. Target-acquisition equipment.

25B7. General operation

The two telescopes are mounted in housings called optical boxes. These boxes are rigidly secured to a transverse frame called the optical box shelf at the front of the director, which can be seen in figure 25B2. The longitudinal axes of the telescopes are in the sight plane, established by the telescope lenses, prisms, and crosshairs. Within the optical box, each telescope is supported in bearings so that it can rotate about its longitudinal axis, which is paralleled to the director roller path at the time of installation. The line of sight is moved in elevation by rotation of a prism within the telescope. The axis of the prism is perpendicular to the longitudinal axis of the telescope and parallel to the horizontal crosshair. The operating principles of the telescope are illustrated in figure 25B5. The crosslevel power drive is geared to both telescopes and turns them about their longitudinal axes. The purpose of this arrangement is to keep the prism axes horizontal, so that the prisms always rotate in a vertical plane. This process is called stabilization in crosslevel.

The rangefinder is installed in a cradle called the rangefinder beam, which in turn is supported in a stand. The stand allows the beam to rotate about an axis lying in the sight plane, parallel to the roller path. The crosslevel power drive is geared to the beam and keeps it stabilized in crosslevel, so that the longitudinal axis of the rangefinder is always horizontal. The radar antenna is similarly stabilized.

The line of sight is kept on the target in train by turning the entire director on its roller path. The amount the director is turned from the fore-and-aft axis of the ship is a measure of director train ($B'r$). Elevation of the line of sight is accomplished by rotating the telescope prisms and by rotating the rangefinder about its longitudinal axis. Rotation of the radar antenna in elevation parallels rotation of the optics. The amount of rotation is the measure of director elevation (Eb).

Train and elevation of the director line of sight are controlled by mechanisms which provide for:

1. *Automatic* (or remote) control of the power drive, modified, as necessary, by the handwheels.
2. *Local* operation of the power drive by means of the handwheels.
3. *Manual* operation by direct gearing from the handwheels.

Train can be accomplished by one of the three means listed above, while elevation is being accomplished by either of the remaining two.

The crosslevel drive holds the sight plane vertical. The Mark 37 director, unlike the main-battery director, has no crosslevel telescope or other means of standby operation in crosslevel.

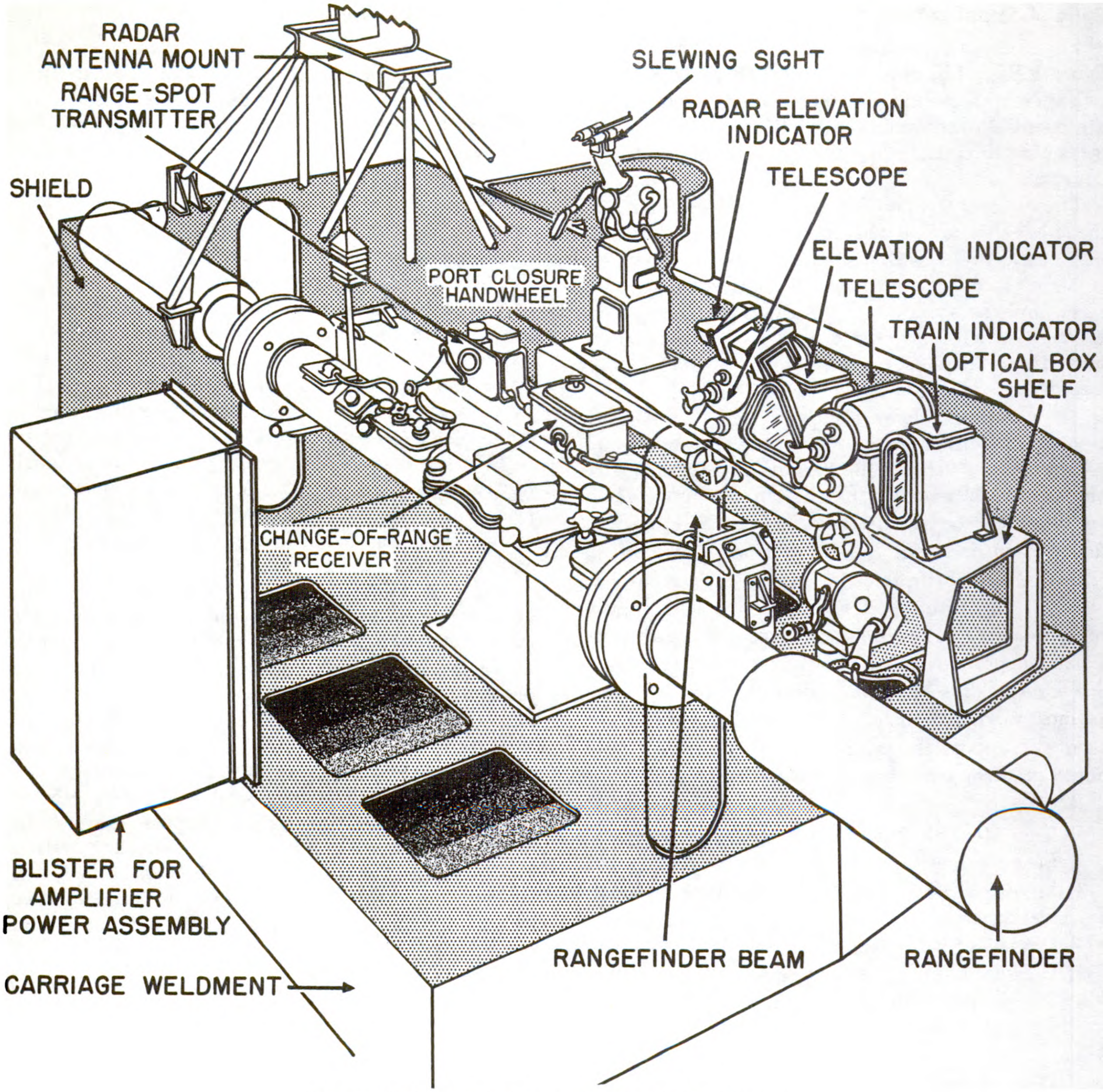


FIGURE 25B2.—Optical equipment inside the director.

25B8. Personnel

Each man of the director crew should be trained to handle any station, so the director can continue to function in the event of a casualty. The personnel act as lookouts through the hatches until they have a target to track.

The control officer is in charge of the entire system. He supervises the director crew, the operators of the computer and stable element, and the crews of guns controlled by his director. He designates the target to his group and, if necessary, estimates target angle (A), target horizontal speed (Sh), and rate of climb, (dH). These estimated quantities he telephones to the computer. The control officer also may make and transmit elevation and deflection spots. He issues battle orders *via* telephone or over an announcing system known as the 17MC, and may control the firing circuit with a portable firing key.

The pointer and trainer keep the director line of sight on the target by turning their handwheels as necessary. They can rate control in elevation and train. Each has a firing key that can be selected to control the firing circuit. Normally, both act as talkers for the control officer.

The rangefinder operator mans the rangefinder and can make range spots in antiaircraft fire. In surface fire he may spot in both range and deflection. Also, he may rate control in range. When the rangefinder is not used, the rangefinder operator assists the radar operator.

The radar operator controls the operation of the Radar Mark 25. He supervises the pointer and trainer in their use of the elevation and train radar scopes. He operates the radar in range, and may rate control in range. In addition, he assists the rangefinder operator when the radar is not in use.

The illumination officer, if one is assigned, acts as assistant control officer and talker for the control officer. He supervises the rear half of the director. He controls any guns firing star shells. Also, when not concerned with illumination, he is available as a relief for any station.

Sometimes a talker is stationed in the director to relay messages from other control centers to the director control officer. Because of space limitations in Mark 37 directors, this seventh station is not usually used unless there is no illumination officer available. Another possible additional station is that of a range talker, who communicates with the plotting room for the rangefinder and radar operators.

25B9. Train control

In general, operation in train and elevation are similar. Differences will be discussed in subsequent articles on elevation control.

In front of the trainer is a selector lever with which he chooses one of the three designated methods of operation, AUTOMATIC, LOCAL, or MANUAL. In manual, the trainer's handwheels are geared directly to the training circle and he supplies the motive power. This method is slow and arduous, and is used only in the event of failure of the power drive.

In local, the gearing between the handwheels and the training circle is disengaged, and the handwheels are connected to the stator of a synchro in the *train receiver-regulator*. Through the receiver-regulator, the synchro controls an electric motor which drives the director. Thus the trainer controls the motion with the handwheels, but the power is supplied by the motor.

Normally, when the target is being picked up and the problem is being set on the computer, the director is operated in local in train. When the computer starts generating a solution, it transmits bearing correction ($\Delta cB'r$) to the director. Then the trainer shifts his selector lever to AUTOMATIC. After an initial solution has been obtained, local control is used only if transmission of $\Delta cB'r$ fails or if targets must be shifted.

Shifting the selector level to AUTOMATIC leaves the handwheels connected to the synchro in the receiver-regulator, as in local. In addition, however, electrical transmission of $\Delta cB'r$ from the computer is connected to the same synchro control transformer. The output of the synchro, then, is the algebraic sum of handwheel motion and $\Delta cB'r$. This sum controls the receiver-regulator, the electric motor, and thus the director's position in train.

Bearing correction ($\Delta cB'r$) is increments of computed change in director train. It takes into account changes in train caused by relative target motion, changes in own ship's course, and the effect of deck tilt. Deck-tilt correction is required to correct train errors introduced by roll and pitch. If $\Delta cB'r$ is correct the line of sight stays on the target without handwheel motion. However, if the bearing correction input is in error, it is the duty of the trainer to bring the line of sight back on target with the handwheels.

25B10. Train rate control

With the director in automatic, if the director tends to drift off the target in train, the trainer can, by closing the rate control key while he keeps the line of sight on the target with his handwheels, introduce a correction into the computer solution. This procedure is necessary if one of the quantities A, Sh, or dH is in error, or if there is a change in target course or speed. If the target becomes obscured, the trainer allows $\Delta cB'r$ to continue to drive the director and sends no rate control signal until the target reappears.

Rate controlling can also be accomplished by the computer operators. The director trainer holds his key closed when on target as in automatic rate control; however, his key actuates a signal at the computer which indicates only that he is on target. This procedure must be used if the director is tracking in local; it may be used at the option of the computer crew with the director in automatic drive.

25B11. Slewing the director

When the director is power driven (local or automatic), the control officer may slew the director in train and elevation. He closes a key on the grip and points the slewing sight (illustrated in figure 25B2) at the target. By this procedure, control of the director is taken away from the pointer and trainer, and the director is driven at high speed until its line of sight coincides with that of the slewing sight. The control officer uses this sight to bring a target into the fields of the optics, and thus *designates* the target to the director crew.

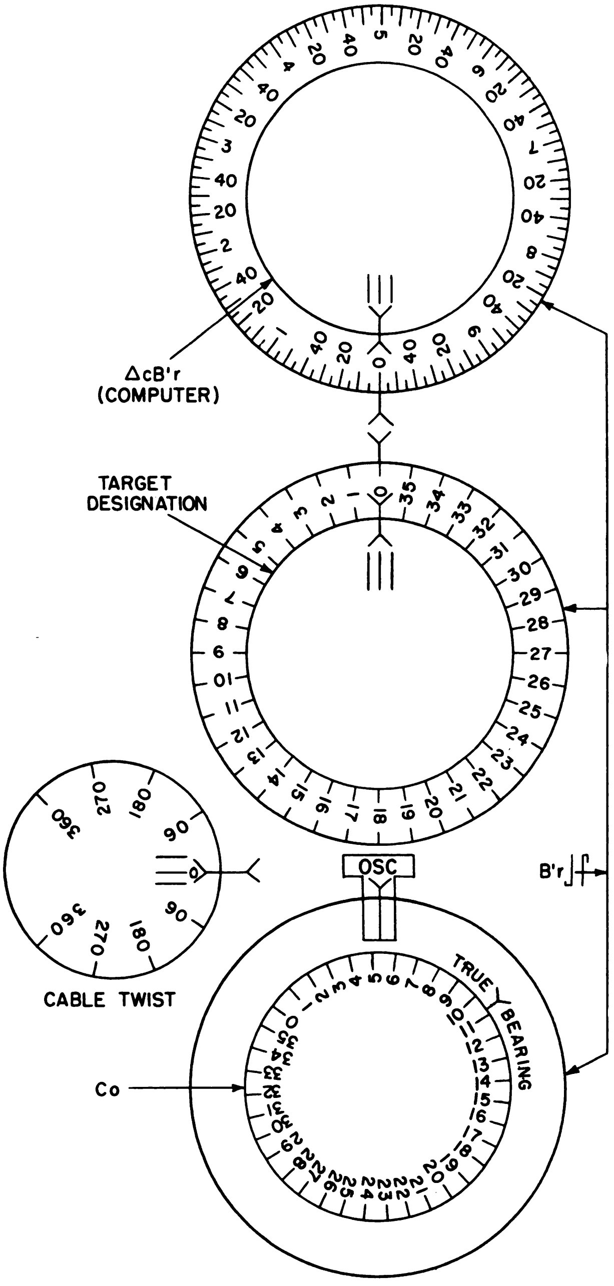


Figure 25B3.—Director train indicator.

25B12. Train and elevation indicators

The train indicator is located on the optical shelf to the right of the trainer's telescope. It receives $\Delta cB'r$ electrically from the computer, and director train ($B'r$) mechanically from the director. It has four dial groups arranged as shown in figure 25B3.

The upper group consists of an inner dial and a ring dial. The inner dial has only a pointer and is driven by $\Delta cB'r$ from the computer in such a way that one revolution of this dial is equal to 10° of $\Delta cB'r$. The ring dial is driven by director train, with one revolution of the dial representing 10° of $B'r$. With the director in local or manual, the trainer can follow the solution by matching the ring dial against the inner dial. If these two dials rotate together, the director is training at the same speed as the computed value. Such procedure would be followed if the target is obscured visually or is lost by the radar.

The center group also consists of an inner dial and a ring dial. The ring dial shows actual director train with one revolution equal to 360° of $B'r$. This dial is graduated in 10° increments and is used in conjunction with the ring dial of the upper group. The inner dial has only a pointer, which is driven by a signal from some unit outside the director for target designation. The trainer picks up a designated target by matching the ring dial against the inner dial.

The bottom group has an inner dial and a ring dial. The ring dial is driven by director train, with one revolution equal to 360° of $B'r$. It has only a single pointer. The inner dial is driven by own-ship course (Co) from zero to 360 degrees. This dial is graduated in 10° increments. By reading the ring pointer against the inner dial, true director bearing is determined. This is useful for locating a target whose true bearing has been supplied by an external source.

At the edge of the indicator face, halfway between the center and bottom groups, is a small dial for reading cable twist. The purpose of this dial is to show how far the director has trained in either direction from its neutral position. In order to protect its connecting cables from excessive twist, the director is limited to 375° of train in either direction from neutral. The dial shows how much farther the director can be trained before the limit stops are reached.

The elevation indicator is secured to the left of the pointer's telescope and below it. This indicator has two dial groups arranged horizontally. It receives elevation correction ($\Delta cE+L+Zd/30$) electrically from the computer, and director elevation (Eb) mechanically from the director. The elevation indicator is shown in figure 25B4.

The left dial group has an inner dial and a ring dial. The ring dial is driven by Eb and is graduated in 2° increments from minus 30° to plus 110°. The inner dial has only a pointer, which is driven by some external unit for target designation.

The right-hand dial group also has an inner dial and a ring dial. The ring dial is driven by director elevation, with one revolution equal to 10° of Eb. The inner dial has only a pointer driven by elevation correction ($\Delta cE+L+Zd/30$) from the computer. In local or manual, the pointer can match these two dials and thus follow the computer solution, should he lose the target temporarily.

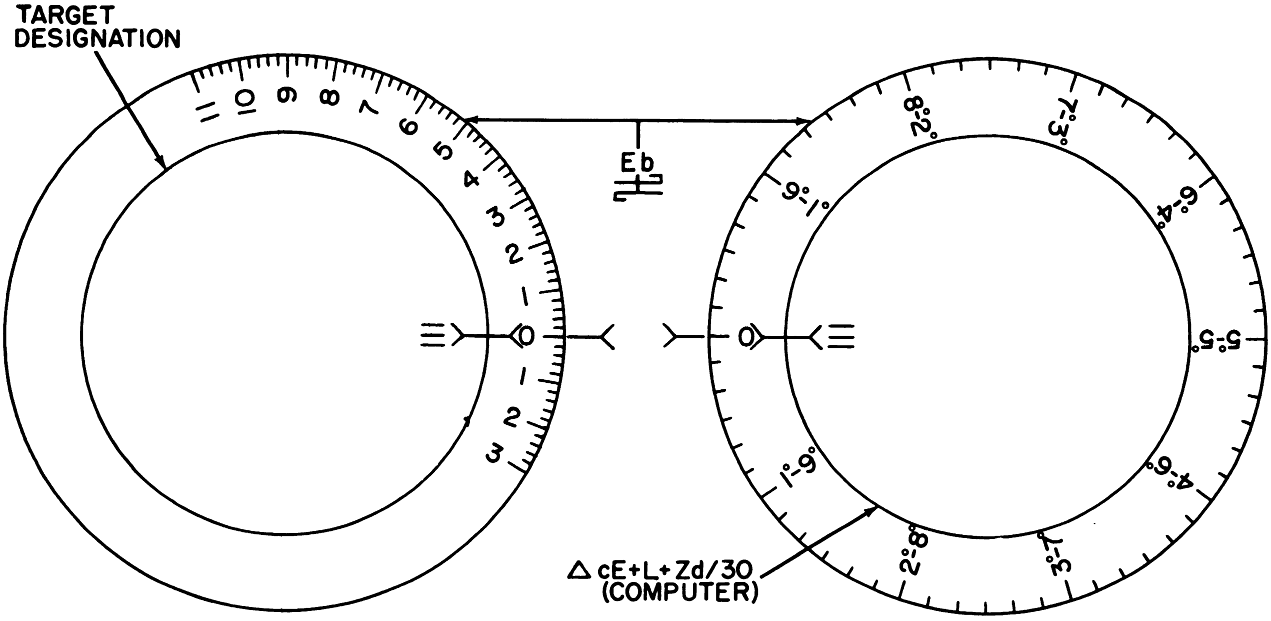


FIGURE 25B4.—Director elevation indicator.

25B13. Elevation

As explained before, the description of director train in article 25B9 is generally true of director elevation. The telescope prisms rotate; the rangefinder rotates about its longitudinal axis; and the radar antenna rotates about its mounting as the pointer follows the target in elevation. In manual the pointer's handwheels are geared directly to the prisms, the rangefinder elevating arc, and the radar antenna elevating gearing. In local or automatic, the electric motor of the power drive is connected and the handwheel connection broken. Then the handwheels are connected to a synchro control transformer in the elevation receiver-regulator. In automatic, elevation is controlled by the algebraic sum of handwheel motion and elevation correction ($\Delta cE+L+Zd/30$).

It can be seen from figure 25A1 that director elevation (Eb) is the sum of target elevation and level angle. ($Eb=E+L$.) To hold the line of sight on the target automatically, changes in elevation due to relative target motion must be supplied. These changes are supplied in the form of increments of generated elevation (ΔcE). It can also be seen that, to hold the line of sight steady, changes in level must be supplied. Therefore, continuous values of L are received from the stable element *via* the computer. L, then, is the second element of elevation correction. Since continuous values of level are received (in automatic) the sights, rangefinder, and radar are said to be stabilized in level. In local or manual, the director is not receiving signals from the computer, and therefore automatic stabilization in level is not possible. Elevation correction is supplied by the pointer's handwheels as he turns them to stay on the target. The elevation operator normally stays in automatic when picking up or shifting targets, so as not to lose the advantage of the level input.

25B14. Crosslevel function

The third element of elevation correction, $Zd/30$, is called crosslevel function. Its purpose is to counteract an error caused by the telescope gearing. Figure 25B5 shows the operating principle of the telescopes. Prism rotation is caused by the input gear driven by the elevation drive. Control of the elevation drive has already been described. The input gear turns the floating gear, which is free to rotate and which acts as a spur gear. This floating gear drives another gear at the end of the worm shaft, turning the worm, which in turn elevates or depresses the prism.

When the telescope is stabilized in crosslevel (figure

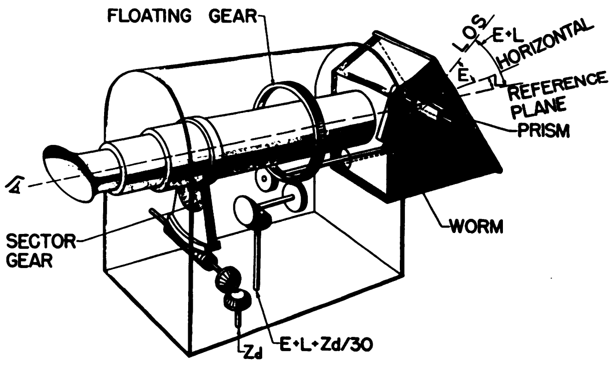
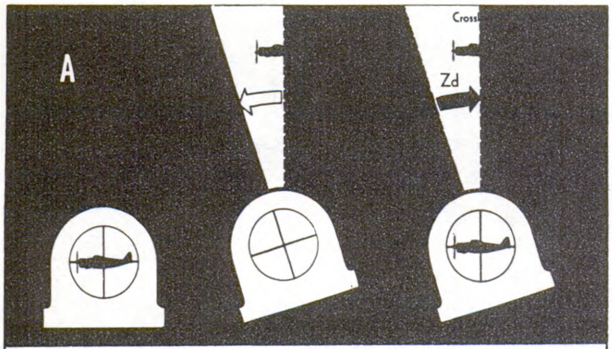
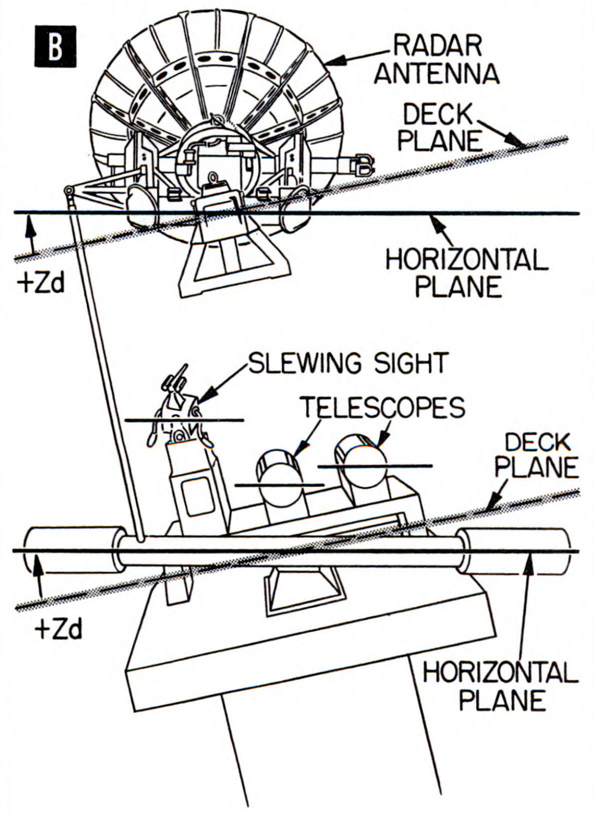


FIGURE 25B5.—Director telescope gearing.



HOW MOTION OF SHIP IN CROSSLEVEL THROWS THE LINE OF SIGHT OFF AN ELEVATED TARGET. LEFT: ZERO CROSSLEVEL--LINE OF SIGHT ON TARGET. CENTER: OPTICAL BOX TILTED IN CROSSLEVEL--LINE OF SIGHT THROWN OFF TARGET. RIGHT: OPTICAL BOX TILTED IN CROSSLEVEL BUT TELESCOPE CROSSLEVELED--STABILIZATION OF THE LINE OF SIGHT KEEPS IT ON TARGET.



STABILIZATION OF LOS KEEPS ELEVATION AXES OF DIRECTOR OPTICS AND RADAR ANTENNA IN THE HORIZONTAL PLANE.

FIGURE 25B6.—Crosslevel stabilization.

25B6), *Zd* drives an input gear which drives the sector gear. Movement of the sector gear causes the telescope to rotate about its longitudinal axis, keeping the prism axis horizontal. However, the worm and its shaft move with the prism. This causes the gear at the end of the worm shaft to walk around the floating gear. Since the floating gear is meshed with the elevation-drive input gear, it cannot be rotated by the worm gear. Thus, the worm gear turns as it walks around the floating gear, introducing an undesired movement of the prism in elevation. Because of the gear ratio used, the error introduced is equal to $Zd/30$. To counteract the error, $Zd/30$ is introduced through the elevation input gear, and rotates the floating gear to eliminate the error as fast as crosslevel stabilization introduces it. $Zd/30$ does not exist as a separate quantity. The stable element generates the combined quantity $L+Zd/30$, which is sent to the computer. In the computer, ΔcE is added to form elevation correction $\Delta cE+L+Zd/30$.

25B15. Crosslevel

Crosslevel stabilization is accomplished by a power drive, consisting of a receiver-regulator and a motor. The motor is connected to the telescopes, rangefinder, and radar antenna. The crosslevel drive rotates the telescopes about their long axes by an angle equal to *Zd*, as shown in figure 25B6. In a similar manner, the whole rangefinder and the radar antenna are rotated about the line of sight by *Zd*. As a result of crosslevel stabilization, the telescope crosshairs, the rangefinder, and the radar antenna are kept horizontal. Consequently, director elevation is measured in the vertical plane, not in the plane perpendicular to the deck as in main-battery directors.

The crosslevel receiver-regulator receives continuous values of *Zd* from the stable element. No method is provided for manual inputs of crosslevel except for a manual arrangement for returning the drive to zero. In the event of a casualty to the crosslevel power drive, the rangefinder and radar antenna are locked at zero crosslevel.

Limit switches are installed in the crosslevel receiver-regulator to protect the equipment. When the value of *Zd* reaches $17\frac{1}{2}°$, the limit switches operate to stop the motor. When the value of *Zd* returns to less than $17\frac{1}{2}°$, the motor cuts in again.

25B16. Range

On the rangefinder beam in front of the rangefinder is a change-of-range receiver, shown in figure 25B7. It contains only a synchro receiver and a servo. Increments of generated range (ΔcR), called range correction, are received by the synchro from the computer. The servo drives the ΔcR signal into a differential in the rangefinder, where it is combined with motion of the rangefinder operator's hand knob to produce an output which positions the rangefinder's measuring wedges. In addition, the differential output positions synchro-transmitter rotors which transmit observed present range (R) to the computer.

The rangefinder operator uses his knob to bring the wander marks above the target. Then, if the computer solution is correct, ΔcR will keep the wander

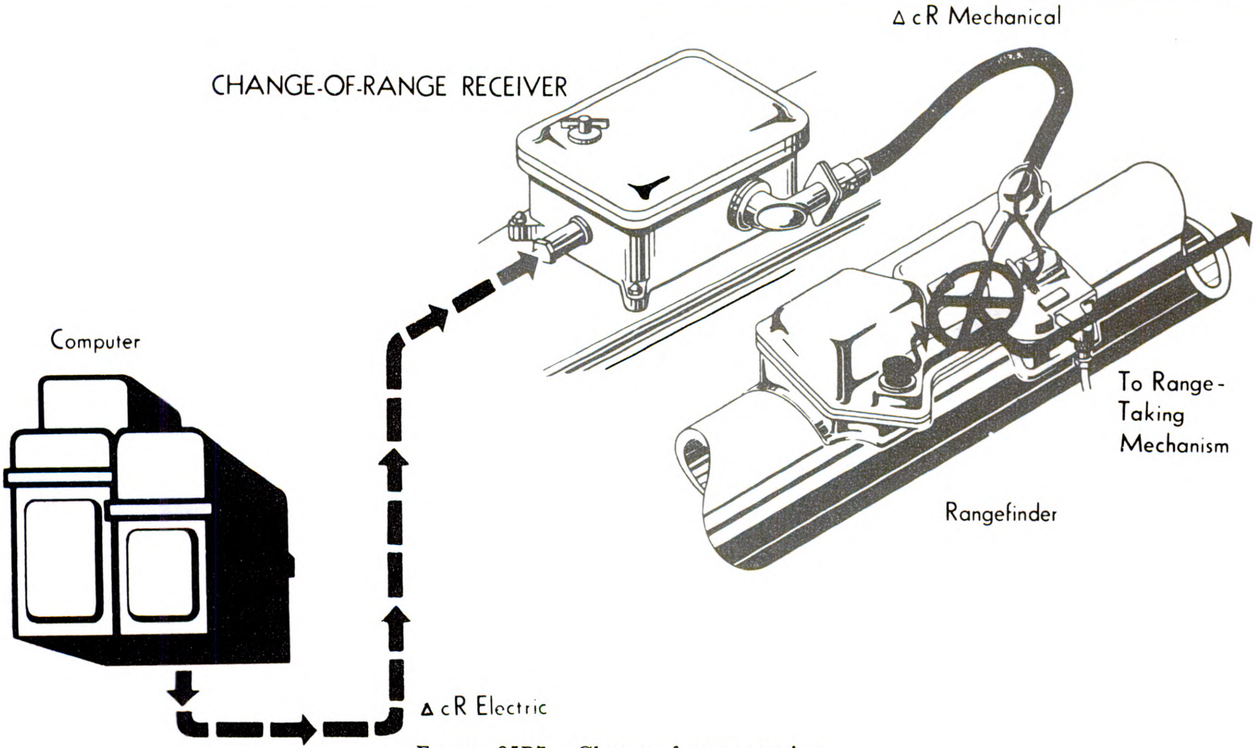


FIGURE 25B7.—Change-of-range receiver.

marks on the target, and the operator merely observes. If the solution is incorrect, the wander marks will drift away from the target, whereupon the operator turns his knob to bring the marks back on target. If either the change-of-range receiver or the ΔcR transmission fails, the operator must do the entire job of keeping the measuring wedges properly positioned. If the transmission of R fails, he must send the values of R to Plot by phone, to be set into the computer by hand.

In the center of the range knob is a button known as the rate control signal button. It is used in the same way as the rate control keys on the pointer's and trainer's handwheels. If the computer is set for automatic range rate control, the operator can rate control in range by pressing the button as he turns his knob. If rate controlling in range is done at the computer, pressing the button tells the computer operators that a correct value of R is being transmitted.

25B17. Spotting

On the rangefinder beam in front of the rangefinder and to the left of the change-of-range receiver is a range-spot transmitter. This transmitter sends both individual and total spot values to the control officer's spot transmitter, but sends only the total value of range spot to the computer. The instrument has one dial group, consisting of an inner dial and a ring dial. The ring dial indicates the value of each individual spot. This dial and its synchro are so geared that, when the spot knob is pushed in, the dial returns to zero. The inner dial shows the value of total range spot transmitted. The knob has 50-yard detents, so the operator can make spots by touch.

To the left of the control officer's station is a spot transmitter. It has three dial groups arranged vertically, each with an inner dial and a ring dial. All three groups show the value of individual spots on the ring dial and the total spot on the inner dial. From top to bottom they show range, elevation, and deflection spots in that order. The top or range group merely repeats what is on the rangefinder operator's range-spot transmitter. There is no range-spot knob on the control officer's spot transmitter, since range spots are transmitted by the rangefinder operator's transmitter. The elevation and deflection dial groups, used by the control officer in spotting, each have a spot knob that functions the same way as the range-spot knob or the range-spot transmitter. These two knobs have 1-mil detents so the control officer can spot by touch. Only total values of elevation and deflection spots are transmitted to the computer by this instrument.

25B18. Illumination control

Star-shell fire is controlled by a star-shell computer attached to the Mark 1A computer. Star-shell gun train, elevation, and fuze-setting orders are calculated by the star-shell computer and transmitted only to the guns firing star shells. Located at the illumination control officer's station in the director is a star-shell spot transmitter. It functions in the same way as the control officer's spot transmitter, except that the spots are star-shell range, elevation, and deflection spots. It has a range-spot knob as well as elevation-spot and deflection-spot knobs.

25B19. Multiple installations

On ships with only one director, the director roller path is the reference plane, and its axis of rotation determines the reference point in train. When more than one director is installed, all must transmit identical values of director train and director elevation for the same reference point. To do this, each director has a roller-path tilt corrector and a horizontal-parallax corrector.

The parallax corrector is in the train receiver-regulator. It receives unit parallax calculated in the computer for a 100-yard horizontal base length. In the receiver-regulator, the electrical signal from the computer is transformed to mechanical movement by a follow-up. Then a simple gear ratio converts unit parallax to the correct amount for the director's actual distance from the reference point. This corrected parallax is fed to a mechanical differential. The other side of the differential receives actual director train. The output is director train corrected for horizontal parallax, which is the value of $B'r$ that would be transmitted by a director actually at the reference point. $B'r$ then is sent to the director train indicator and to the computer.

Should parallax transmission or the follow-up fail, manual application of parallax is possible. Two concentric parallax dials are located in the face of the train receiver-regulator. The ring dial is graduated for unit parallax, and is driven by the follow-up mechanism. The inner dial has only a pointer and is driven by the parallax synchro-receiver. When the follow-up mechanism fails, a hand crank is used to match the zero on the ring dial against the pointer on the inner dial. This causes the correct parallax to be introduced. If parallax transmission fails, unit parallax can be received by phone and set on the outer dial against a fixed index. In either of these two cases, the crank performs the function of the follow-up.

The roller-path tilt corrector is located on the director carriage. Inclination of the director roller path from the reference plane is corrected in accordance with alignment data determined as described in chapter 21. Roller-path inclination in the sight plane is a function of the angle of director train from the high point. Director train $B'r$ is a mechanical input to the tilt corrector. The train value of the high point and the inclination of that point are set on the mechanism after alignment has been checked. The output of the corrector is combined with director elevation above the roller path. The result is director elevation above tne reference plane (Eb).

25B20. Radar

The Mark 25 radar is an automatic tracking fire control radar. Its antenna and parabolic reflector are mounted atop the director. Indicator scopes and other associated components are located in the director and below decks. This radar provides for three types of antenna scan: *spiral* for target acquisition, *conical* for tracking, and *circle* for spotting shell splashes in surface fire.

In normal operation, the automatic tracking feature relieves director personnel of making rate control corrections. Tracking signals—representing target range, bearing, and elevation—are generated from the radar information and compared with the generated range, bearing, and elevation from the computer. Any differences between the computer and radar quantities are transmitted to the director as corrections, to reposition it in accordance with the radar information.

The corrections, in turn, are transmitted to the computer, where they correct its solution until it matches the radar valves. Once the target has been acquired by the radar, this process is continuous and automatic.

Characteristics of the Mark 25 radar are described in volume 3 of this course.

C. Computer

25C1. General

This section describes the Computer Mark 1A (fig. 25C1). The Computer Mark 1A is the mechanical brain of the Gun Fire Control System Mark 37, which is used to control the fire of dual-purpose guns against both air and surface targets.

The Computer Mark 1A computes continuous gun orders containing corrections for all the significant factors affecting antiaircraft and surface fire. The corrections allow for motion of own ship and target during the time the projectile is in flight; for the curvature of the projectile path caused by gravity, drift, and wind; for pitch and roll of the ship; and for a number of other factors.

These gun orders, a fuze-setting order, and parallax corrections are continuously transmitted from the computer to the gun mounts. At the mounts, these orders are used to point the guns continuously, and to time the fuzes so that the projectiles will explode at the predicted position of the target.

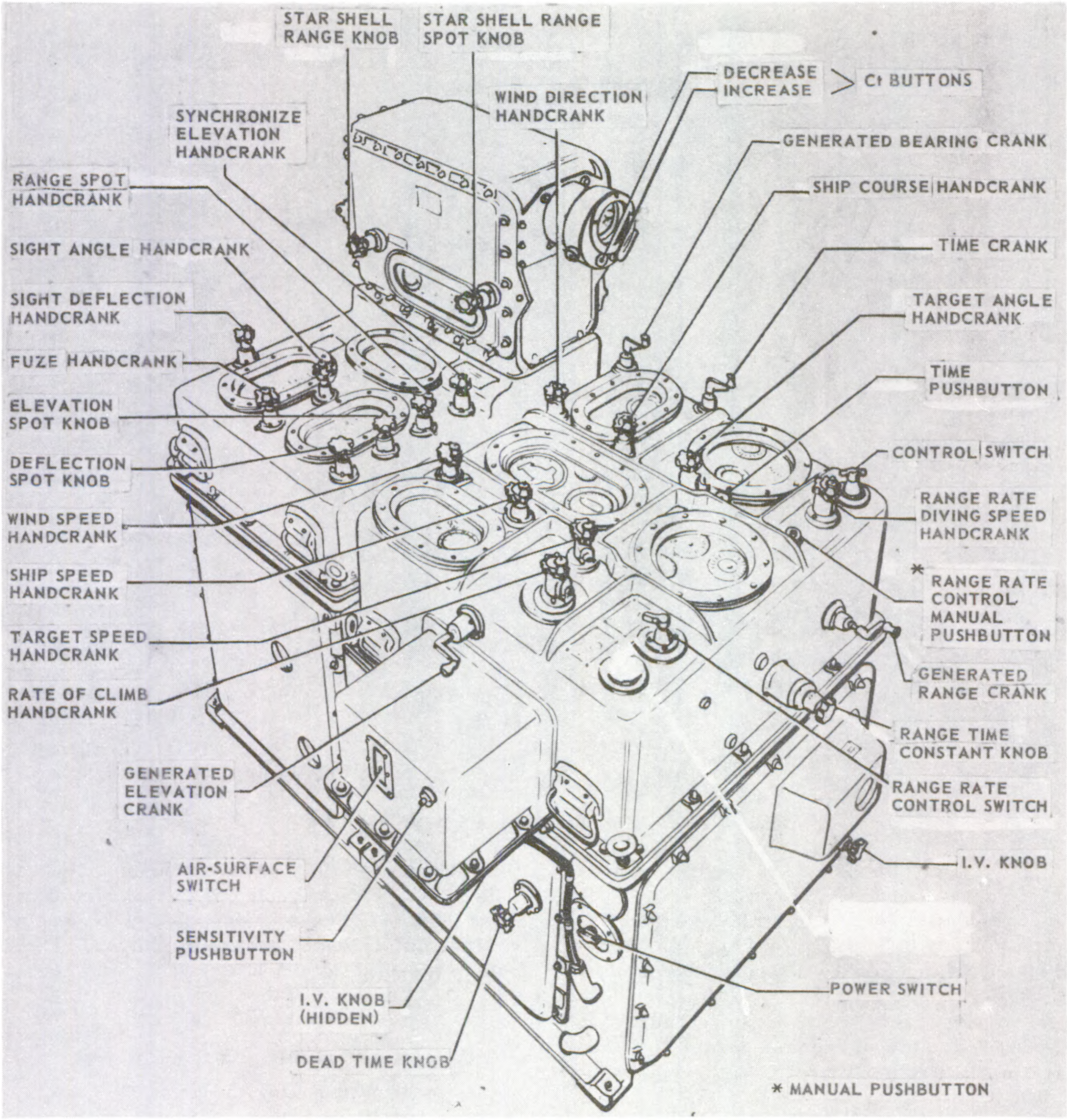


Figure 25C1.—Computer Mark 1A, operating controls.

Modifications of Computer Mark 1A have been developed to control the various calibers of dual-purpose guns in use in the Fleet. All modifications are essentially the same in appearance, function, and operation. They differ mainly with respect to the self-contained ballistic data which adapt them to a particular gun.

The Star-Shell Computer Mark 1, which is installed on top of the Computer Mark 1A as an integral part, also will be described in this section. In this text, when the main computer is referred to it is called merely the computer. The auxiliary instrument is always called the star-shell computer. Both instruments are shown in figure 25C2.

25C2. Functions

The computer functions are:

1. To permit the dual-purpose guns to be pointed and trained, and fuzes and sights to be set continuously for either AA or surface fire against a common target.

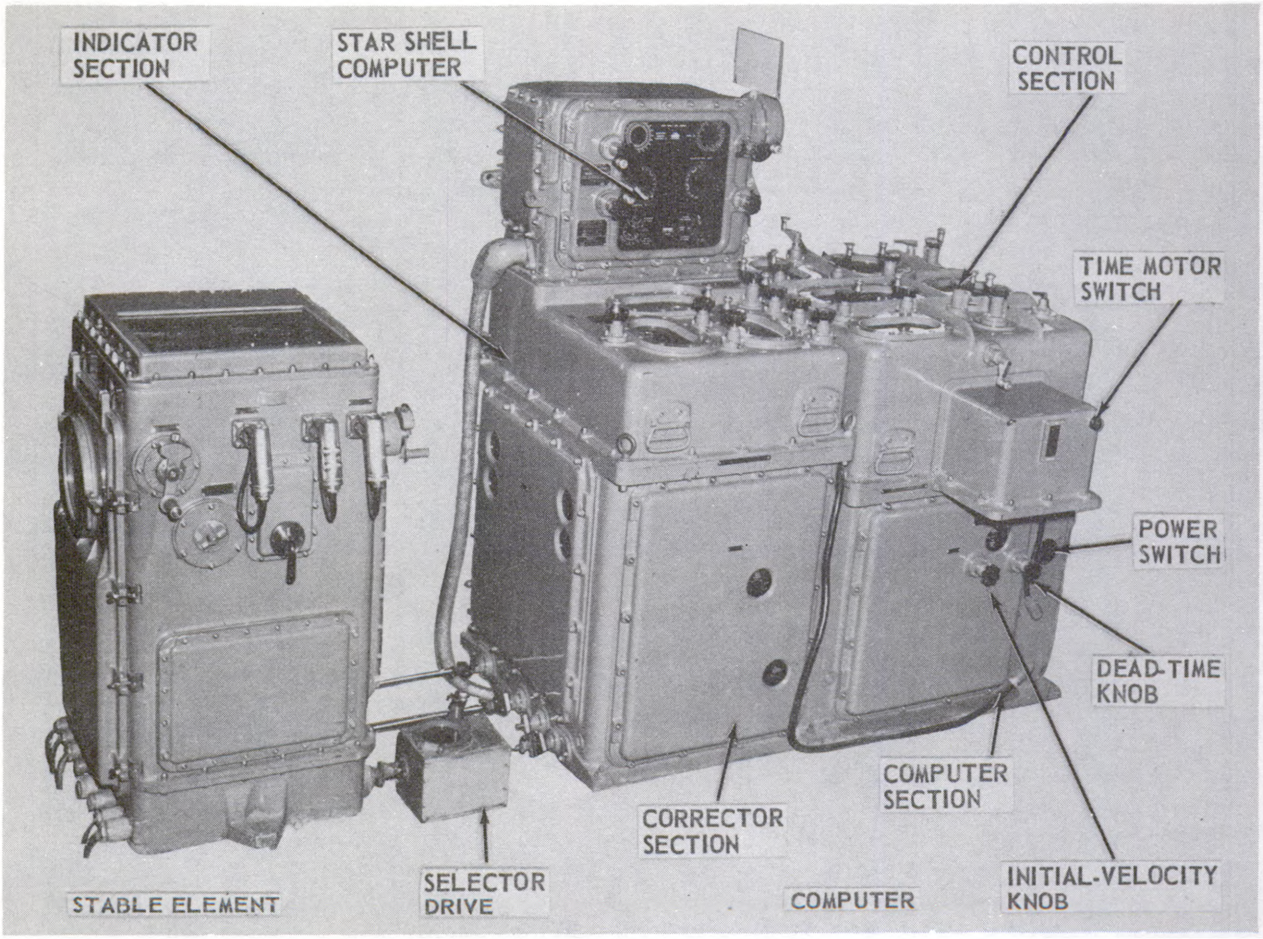


FIGURE 25C2.—Computer Mark 1A and stable element.

2. To aid the director crew in keeping the line of sight on target in either air or surface fire.

3. With the star-shell computer, to permit the dual-purpose battery to be pointed and trained, and fuzes to be set continuously for illumination of a surface target.

4. To permit, as an alternative to *1,* control of the 40-mm or 3″/50 rapid-fire guns at short ranges, and the main battery in barrage fire against a common target.

The computer makes nearly all of the calculations required for control of the dual-purpose battery that can be computed centrally. This permits standardization of equipment and increases the flexibility in multiple installations. It also permits the Mark 37 system to be used on any type of ship large enough to support its weight.

25C3. Outputs

The computer calculates and transmits the quantities listed below. Some are for both single and multiple installations, while some are for multiple installations only. *Pv* is used only on large carriers of the *Essex* and *Midway* types. Figure 25A3 shows graphically the distribution of most of the outputs. These outputs are supplied as follows:

Electrically to Guns

1. *B′gr*—Gun train order, automatic.
   B′gr—Gun train order, indicating.
2. *E′g*—Gun elevation order, automatic.
   E′g—Gun elevation order, indicating.
3. *Ph*—Train parallax for a 100-yard horizontal base.
4. *Pv*—Elevation parallax for a 100-yard horizontal base.
5. *F*—Fuze-setting order for mechanical fuzes.
6. *Ds*—Sight deflection.
7. *Vs*—Sight angle.

Electrically to Director

1. $\Delta cB'r$—Bearing correction, automatic.
   $\Delta cB'r$—Bearing correction, indicating.
2. $\Delta cE+L+Zd/30$—Elevation correction, automatic.
   $\Delta cE+L+Zd/30$—Elevation correction, indicating.
3. ΔcR—Range correction.
4. Ph—Train parallax for a 100-yard horizontal base (multiple installations only).

Mechanically the Star-Shell Computer

1. $B'gr$—Gun train order.
2. $E'g$—Gun elevation order.
3. $R2$—Advance range.
4. $WrD+KRdBs$—Star-shell deflection rate.

Mechanically to the Stable Element

1. $B'r$—Director train.

In the list above, where the same signal is transmitted both in automatic and in indicating, the signal is identical. It is sent over separate circuits following different paths to separate synchro receivers at the directors or mounts. This feature enables one transmission line to be used if the other is damaged. One controls the power drive and the other moves indicator dials. Use of the circuits can be exchanged, should the need arise, by suitable switching arrangements at the fire control switchboard.

Elevation parallax for a vertical base (Pe) is included in sight angle (Vs), and therefore in gun elevation order ($E'g$). It does not exist as a separate quantity.

Sight angle and sight deflection are each received by a single synchro (coarse) on single mounts. On twin mounts these values are received by a pair of synchros (fine and coarse). Since the speeds of the course receivers are not the same on the two types of mount, the computer uses a different set of transmitters for the single and twin mounts.

25C4. Inputs

The computer receives the following inputs from the sources and by the methods indicated:

Mechanically from Stable Element

1. L—Level (or Lj—selected level).
2. Zd—Crosslevel (or Zdj—selected crosslevel).
3. $L+Zd/30$—Level plus crosslevel function.

Electrically from Director

1. Eb—Director elevation.
2. $B'r$—Director train.
3. R—Observed present range (may be received by phone).
4. Dj—Deflection spot (may be received by phone).
5. Vj—Elevation spot (may be received by phone).
6. Rj—Range spot (may be received by phone).
7. Rate control of *on target* signals for range, elevation, and bearing.

Electrically from Gyro Compass and Pitometer Log

1. Co—Own-ship course.
2. So—Own-ship speed.

By Phone from Director, Put in Manually

1. A—Target angle, initial or corrective value.
2. Sh—Target's horizontal speed, initial or corrective value.
3. dH—Rate of climb, initial or corrective value.

Manually: Calculated or Estimated in Plotting Room

1. As an alternative to 7, above, rate control values for range.
2. dR—Direct range rate (target diving speed).
3. Bw—True direction true wind.
4. Sw—True wind speed.
5. jBr—Initial relative target bearing.
6. jE—Initial target elevation.
7. jR—Initial range.
8. $I.\ V.$—Initial velocity.
9. Tg—Dead time.
10. Dip angle.

25C5. Principles

A detailed discussion of the principles of basic mechanisms used in mechanical computers has been given in section E of chapter 19. The present section provides a brief description of the calculations made within the computer.

The computer solution of the AA problem is in many respects similar to the solution of the surface problem by the rangekeeper described in chapter 19. The computer computes relative target motion rates which are used in generating cR, cBr, and cE. The effects of changes in Co are taken into account in the case of cBr. Since the computer was developed before radar became reliable, it was designed for rangefinder ranges. Because rangefinder ranges are somewhat erratic at best, the computer uses generated range (cR) for its calculations. This improves the smoothness of operation of the instrument. Measured relative target bearing (*Br*) and target elevation (*E*) are used for computations, because they can be measured accurately and smoothly. The target elevation (*E*) is obtained by subtracting level (*L*) from director elevation (*Eb*). ($E=Eb-L$). Relative target bearing (*Br*) is obtained by adding deck-tilt correction (*jB′r*) to director train (*B′r*). ($Br=jB'r+B'r$.)

Also, in keeping with methods used in the surface rangekeeper, the computer generates increments of range, relative bearing, and elevation (ΔcR, $\Delta cB'r$, and ΔcE). $\Delta cB'r$ is sent to the director train receiver-regulator to move the line of sight according to the generated value of director train. It takes into account both deck-tilt correction and changes of own-ship course. Thus, if the solution is correct $\Delta cB'r$ will keep the line of sight on the target in train while the ship rolls, pitches, and changes course. As explained in article 25B9, this is only when the director train power drive is in automatic. $\Delta cB'r$, when used as described above, is called bearing correction. ΔcE is added in the computer to level correction (*L*) and crosslevel function (*Zd*/30). The sum ($\Delta cE+L+Zd/30$) is called elevation correction. It is sent to the director elevation receiver-regulator to hold the line of sight on target in elevation. This it will do only if the director elevation power drive is in automatic and if the computer solution is correct.

These changes in director train and elevation caused by bearing and elevation corrections show up in new values of director train (*B′r*) and director elevation (*Eb*). Thus there is a continuous feedback into the computer, since the director transmits *B′r* and *Eb* continuously to the computer. In other words, the computer and director together form a regenerative group. This allows the director to follow an obscured target by riding the computer solution. As long as the solution is correct, the director will remain on the target. This regenerative arrangement also permits indirect fire against a temporarily obscured target. This is accomplished in a manner similar to that described in chapter 19 for a surface rangekeeper. In addition, the computer is so arranged that generated bearing (*cBr*) can be used for calculations in surface fire. When this arrangement is used, the computer is regenerative in bearing within itself and can control indirect fire without director inputs.

Ballistics, too, are computed in the same manner in the computer as they are in the surface rangekeeper. That is, the three linear rates (*dR, RdE,* and *RdBs*), generated present range (*cR*), and certain other necessary quantities are used. Actually, the computer develops advance range (*R*2) and predicted target elevation (*E*2) by a series of approximations. Using the advance target position, computations of ballistics are essentially the same as those developed in section 24B.

Because approximations are used in the computer, certain variations from the analytical solution exist. Some of these are:

1. Wind computations are empirical equations, based on an approximation of the line of fire.
2. Air-density corrections are separately computed, and applied to the computer as a change in initial velocity.

While the standard new-gun initial velocity for the 5″/38 gun is 2,600 foot-seconds, the computer calculations are based on an I. V. of 2,550 foot-seconds. This reduces the size of the maximum corrections which may have to be applied, and thus increases the accuracy of the average correction. Corrections may be automatically calculated for any variation of initial velocity between the standard (2,600 fs) and the lower limit (2,350 fs) which is set into the computer.

The elements considered in the computation of sight angle, sight deflection, and fuze-setting are:

Vs—Sight angle

1. *Vt*—Elevation prediction.
2. *Vf*—Superelevation.
3. *Vw*—Wind elevation correction.
4. *Vfm*—Initial velocity elevation correction.
5. *Vx*—Complementary error.
6. *Pe*—Elevation parallax correction for a 30-foot vertical base.
7. *Vj*—Elevation spot.

Ds—Sight Deflection

1. *Dt*—Deflection prediction.
2. *Dfs*—Drift.
3. *Dw*—Wind deflection correction.
4. *Dj*—Deflection spot.

F—Fuze Setting

1. *Tf*—Time of flight.
2. *Tg*—Dead time.

The basic gun train and elevation orders have been discussed in chapter 24. Briefly, gun train order (B′*gr*) is equal to director train (*B′r*) plus deck deflection (*Dd*). ($B'gr=B'r+Dd$.) Deck deflection is equal to partial deck deflection (*jDd*) and trunnion-tilt train correction (*Dz*). ($Dd=jDd+Dz$.) Gun elevation order (*E′g*) is equal to director elevation (*Eb*) plus sight angle (*Vs*) plus trunnion-tilt correction in elevation (*Vz*). ($E'g=Eb+Vs+Vz$.) *B′gr* is corrected for horizontal parallax (*Ph*) at the gun, while *E′g*, as transmitted by the computer, includes the correction for vertical parallax (*Pe*). On large carriers, *E′g* is further corrected *at the guns* for vertical parallax caused by horizontal displacement (*Pv*).

25C6. Rate control

1. *General.* As previously explained, the computer determines the relative motion rates (*dR, RdE,* and *RdBs*) from the primary data indicated below:

a. Estimated or computed: target angle (A), target horizontal speed (*Sh*) and rate of climb (*dH*).

b. Measured: Present range (*R*), relative target bearing (*Br*), target elevation (*E*), own-ship speed (*So*), own-ship course (*Co*), and time (*T*).

From these relative motion rates, generated target position is computed (*cR, cBr,* and *cE*). Since the relative motion rates as well as the generated or computed value of range (*cR*) are used in the calculations for ballistics and predictions, it is necessary that these values be accurate for gun orders to be correct.

If the primary data listed above are correct, the relative motion rates will be correct and the generated target position values (*cR, cBr* and *cE*) will agree with the observed target position values (*R, Br,* and *E*). If the primary data are not correct, however, the relative motion rates will be incorrect, and the generated target position values will not agree with the observed target position values; consequently gun ballistics and predictions and, therefore, gun orders will be in error.

Since the measured quantities of the primary data are determined by instruments, their accuracy is relatively high; consequently, whenever there is disagreement between generated and observed values of present target position, the likeliest source of error is in the quantities *A, Sh* and *dH*.

By adjusting the quantities *A, Sh,* and *dH,* the relative motion rates (*dR, RdE* and *RdBs*) can be corrected, bringing *cR, cBr* and *cE* into agreement with *R, Br* and *E*. The method by which this is accomplished is known as *rate control.*

It is a simple matter to arrange a set of dials that will indicate disagreement between the actual and computed values of range, bearing, and elevation. For example, consider target elevation, and assume a dial group like that in figure 25C3. The outer ring dial is driven by measured or actual target elevation (*E*). The computer, receiving director elevation (*Eb*) from the director, combines *Eb* with level angle (*L*) in a differential to produce target elevation, one use of which is to drive the observed elevation dial. The inner dial is driven by generated target elevation (*cE*) as determined by the computer.

As the director LOS follows the target, changes in target elevation will obviously cause the outer ring dial to rotate. The speed of rotation will be proportional to the actual elevation rate. Changes in generated elevation drive the inner dial at a speed proportional to the computed elevation rate (*RdE*). Equal rotational speeds of the outer ring dial and the inner dial are apparent when the inner dial marks remain stationary with respect to the outer ring dial marks. This condition signifies that the computed elevation rate equals the actual elevation rate. When the dials turn at different speeds, the computed rate (*RdE*) is evidently wrong and must be corrected by correcting the quantities *A, Sh* and *dH*. This same process can be applied to compare the computed and actual range and bearing rates.

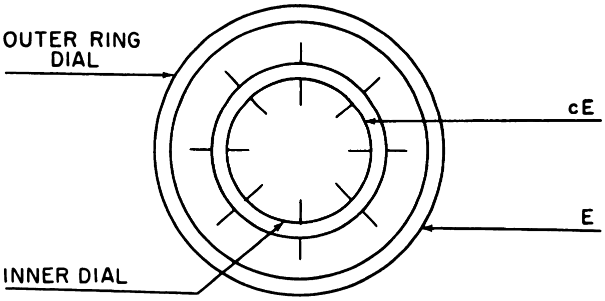


FIGURE 25C3.—Comparison dials.

Rate controlling can be accomplished with the director in automatic, local, or manual drive operation. Since operation of the director in automatic provides optimum use of the rate control features of the Computer Mark 1A, the ensuing discussion will consider the rate control features of the director with its power drives in automatic.

In this condition, ΔcR, $\Delta cB'r$, and $\Delta cE + L + Zd/30$ will keep the director automatically on the target without handwheel motion by the pointer and trainer as long as the solution remains correct. Also, the rangefinder wander marks will keep on the target and the radar target pip will remain in the range notch.

If the solution is not correct, it is necessary for the director pointer and trainer to use their handwheels, with their rate control keys depressed, to keep the LOS on the target. If the LOS gets off the target, the rate control keys should be released, and should not be closed until the crosswires are back on target. Rate control keys should be closed only when the crosswires are on the target. Similarly, if the solution is not correct, the rangefinder operator and radar operator will have to use their range controls to keep the wander mark on target and the pip in the notch. While on target in range, the rate control keys should be depressed. However, if the operators get off in range, the rate control keys should be released until the operators get back on target.

2. *Rate control symbols.* In addition to the symbols previously covered in the course, the following symbols are used in the analysis of rate control:

jBr—Angular bearing rate correction.
jE—Angular elevation rate correction.
jdR—Direct range rate correction.

These values represent the angular differences between the generated and observed changes in bearing, elevation, and range, and are used in the rate control mechanism to correct the quantities *A, Sh,* and *dH.* When *jBr* and *jE* are multiplied by a value of range (as will be explained later) they provide the linear bearing and elevation rate corrections applied to the rate control mechanism:

jBc—Linear bearing rate correction. The rate correction primarily affecting linear deflection rate (*RdBs*).

jEc—Linear elevation rate correction. The rate correction primarily affecting linear elevation rate (*RdE*).

As will be explained in article 25C7, *jdR* in the slant plane is converted to the horizontal plane, resulting in the following quantity:

jdRh—Horizontal range rate correction. The rate correction primarily affecting horizontal range rate.

The following symbols will be used to represent the final rate control mechanism corrections to *A, Sh,* and *dH.*

jSh—Target horizontal speed correction.
jHc—Rate-of-climb correction.
jCt—Target angle (course) correction.
jRc—Linear range correction.

3. *Methods of rate control.* In the Computer Mark 1A, provision is made for two methods of rate control. These are automatic and manual rate control. Automatic rate control is made possible by the inclusion of a rate control computing mechanism in the computer. When employed, this mechanism will compute and correct the target motion rates *A, Sh,* and *dH* for targets at speeds of 15 knots to 800 knots. The rate control mechanism is not designed to operate accurately below target speeds of 15 knots; hence, for the lower-speed targets, manual rate control should be employed.

Selection of the method of rate control is made at the computer by positioning the *control switch* and the *range rate control switch.* The control switch governs the method of bearing and elevation rate control. The range rate control switch governs the method of range rate control.

a. Automatic rate control. Automatic rate control is the normal method of operating Computer Mark 1A for all air targets and for surface targets at speeds of 15 knots and over.

In automatic rate control, follow-up motors in range, bearing, and elevation are employed to keep the generated dials continuously rotating at the same rate as the observed dials. Figure 25C4 shows the flow diagram for bearing and elevation. *Br* and *E* are obtained from inputs of director train and elevation ($Br = B'r + jB'r$ and $E = Eb - L$). ΔcBr and ΔcE are obtained from the computer tracking section [$\Delta cBr = \Delta T\ (dBr)$ and $\Delta cE = \Delta T(dE)$].

The generated and observed values of bearing and elevation are compared in a differential, the output of which is used to close the contacts on the follow-up motors. The output of these follow-up motors, as well as the increments of generated bearing and elevation, is used to drive the generated dials. When the generated value equals the observed value, the output of the differential will be zero, the contacts to the follow-up motor will open, and the follow-up motor will stop driving the generated dials. If the computed rates, *dBr* and *dE,* are correct, *cBr* and *cE* will keep the generated dials changing at the same rate as the observed dials. Any error in the computed rates, however, will cause the follow-up motors to drive to keep the generated dials rotating at the same rate as the observed dials.

A range follow-up motor is employed to drive the generated range dial into agreement with the observed range dials, although, as will be explained later, the method of accomplishing this varies from that employed with bearing and elevation.

When the director operators close the rate control keys, the signal not only is transmitted to the computer ON TARGET indicators, but also is used to close clutches between the output shafting of the follow-up motors and the input shafting to the rate control mechanism. The *jBr* clutch and *jE* clutch are shown on figure 25C4. Thus when the director rate control keys are closed and an error exists in the computed rates (*dR, dBr* and *dE*), the output of the follow-up motors will drive into the rate control mechanism.

In this manner, when an error exists, the rate control mechanism automatically receives the rate corrections *jdR, jBr,* and *jE,* the differences between the rates of change of generated and observed range, bearing, and elevation. The rate control mechanism then will correct the values of *A, Sh,* and *dH,* thereby causing the computer to compute new target motion rates (*dR, dBr,* and *dE*). The new target motion rates will result in new values of ΔcR, ΔcBr, and ΔcE to drive the generated dials. In addition, since target motion rates are used in the computer prediction and correction sections, the computer will compute new and more accurate gun orders.

b. Manual rate control. Manual rate control must be used when the rate control mechanism is inoperative, for indirect fire when observation of the target is impossible, and for surface targets below a speed of 15 knots. In this method, initial values of target angle, target horizontal speed, and target rate of climb must be estimated and set manually into the

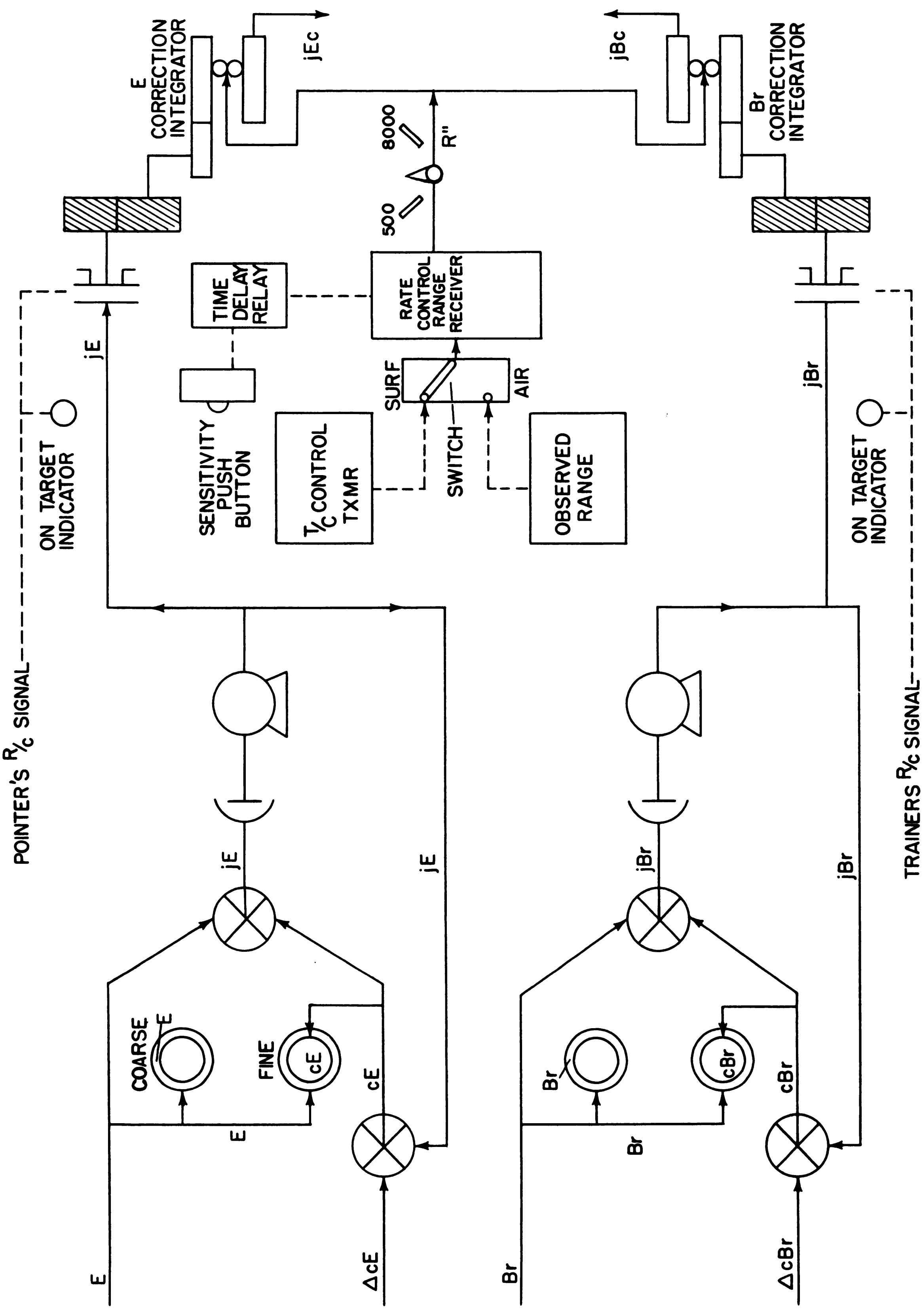


FIGURE 25C4.—Bearing and elevation control with sensitivity network.

computer. When the director rate control keys are closed, signals appear at the computer ON TARGET indicators. Computer personnel then know that the director is on target and the correct values of *R, Br,* and *E* are indicated on the comparison dials. If the generated dials are not rotated at the same speed as the observed dials, the initial estimates of *A, Sh,* and *dH* were incorrect, and are changed manually until all comparison dials are rotating together. In addition, the computer range operator must ensure that the correct value of range is continuously set on the range dials.

It should be evident that initial estimates of *A, Sh,* and *dH* depend upon the skill of the control officer. Even the most experienced officers cannot estimate these values within close enough limits to ensure accuracy of the solution; consequently a correct solution generally requires changing manually the initially estimated values. For this reason, and because of the short duration of the air problem, manual rate control is considered an auxiliary type of operation for air targets.

25C7. Rate control mechanism

1. *Analytical solution.* The function of the rate control mechanism is to correct the values *A, Sh,* and *dH.* By analyzing the differences between changes in generated and observed values of range, bearing, and elevation (*jdR, jBr,* and *jE*), this mechanism determines what errors in *A, Sh,* and *dH* were responsible for such differences, and corrects the errors. Once *A, Sh,* and *dH* are corrected, the computed relative motion rates should be correct and, therefore, the gun orders should be accurate.

Figures 25C5 and 25C6 show analytically and by flow diagram how the rate control mechanism solves the problem. In studying the figures, the following symbols are used:

jBr—Angular bearing rate correction.
jBc—Linear bearing rate correction.
jE—Angular elevation rate correction.
jEc—Linear elevation rate correction.
jdR—Direct range rate correction.
jdRh—Horizontal range rate correction.
jSh—Target horizontal speed correction.
jHc—Rate-of-climb correction.
jCt—Target angle (course) correction.

Since the basic mechanisms employed in the rate control mechanism require linear inputs, the angular bearing and elevation rate corrections (*jBr* and *jE*) must be converted into linear bearing and elevation rate corrections (*jBc* and *jEc*). As shown in figure 25C5, the linear rate corrections in the vertical plane through the line of sight (*jEc* and *jdR*) are resolved into horizontal and vertical components. The horizontal components are combined to produce horizontal range rate correction (*jdRh*). The vertical components are combined to produce rate-of-climb correction (*jHc*). The latter correction, *jHc,* is used to correct target rate of climb (*dH*).

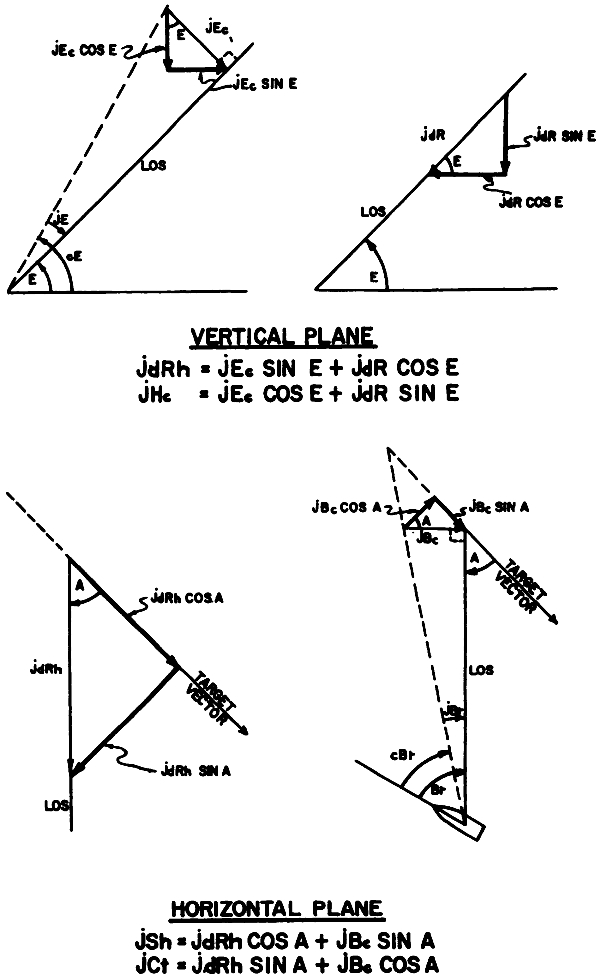


FIGURE 25C5.—Rate control analytical solution.

$$jdRh = jEc \sin E + jdR \cos E.$$
$$jHc = jEc \cos E + jdR \sin E.$$

The horizontal range rate corection (*jdRh*) and the linear bearing rate correction (*jBc*), both of which lie in the horizontal plane, are resolved into components in and perpendicular to the target vector as shown in the figure. The components which lie in the target vector are combined to produce target horizontal speed correction (*jSh*). The components perpendicular to the target vector are combined to produce target course correction (*jCt*). These values

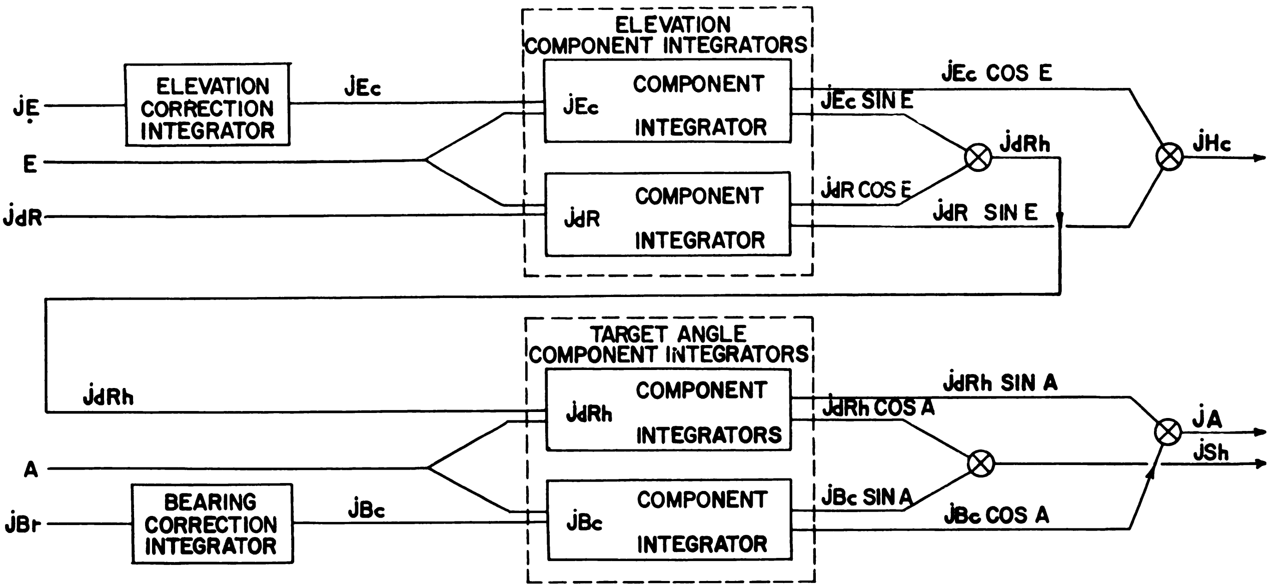


FIGURE 25C6.—Component integrator flow diagram.

are used to correct target horizontal speed (*Sh*) and target angle (*A*) or target course (*Ct*).

$$jSh = jdRh \cos A + jBc \sin A.$$
$$jCt = jdRh \sin A + jBc \cos A.$$

2. *Basic mechanisms employed.* The basic mechanisms employed to resolve the rate corrections as explained above are four component integrators. These mechanisms perform the same functions as component solvers. The differences in construction, however, enable the component integrator to handle rapidly changing inputs throughout an unlimited range of values, whereas the component solver is limited in the range of the inputs it can handle.

The inputs of the component integrator, a changing angular value and a changing linear value, establish a vector which has length and direction. As shown in figure 25C6, the angular input to the elevation component integrators is target elevation (*E*), and the angular input to the target angle component integrators is target angle (A). Since the second input to each must be linear, bearing and elevation correction integrators (disc type) are employed to convert the angular rate corrections (*jE* and *jBr*) into linear rate corrections (*jEc* and *jBc*). The correction integrators have a further function in controlling computer sensitivity, which will be discussed later. Note in the figure that two of the outputs of the *jdR* and *jEc* component integrators are combined to produce *jdRh*, the linear input to the *jdRh* component integrator.

These integrators continuously resolve the changing vector into sine and cosine functions of the vector input. The sine and cosine functions are combined into the required corrections, *jCt, jSh,* and *jHc,* as indicated in the figure. As previously stated, when *A, Sh,* and *dH* are corrected, new values of *dR, RdE,* and *RdBs* are computed which give more accurate gun orders.

25C8. Computer sensitivity

The rate control system of Computer Mark 1A includes sensitivity units which control the time required by the computer to reduce errors in generated rates to the point where the corrected rates are sufficiently accurate to compute adequate gun orders. Sensitivity may be thought of as the speed with which the errors are corrected by the rate control mechanism. If the errors are corrected within a relatively short time interval, the sensitivity is considered to be high, and if the errors are corrected within a relatively long time interval, the sensitivity is considered to be low.

The time interval used is called the time constant (*Tc*), and is defined as the time in seconds required to reduce a rate error to an acceptable figure, or 37% of its initial value. Thus a low time constant will give high sensitivity, and a high time constant will give a low sensitivity. For example, assume a direct range rate error (*jdR*) of 100 yd/sec, and accurate ranging by the rangefinder or radar operator. If the *Tc* is 2 seconds, the 100 yd/sec error would be reduced to a 37 yd/sec error in 2 seconds, and the sensitivity of the range rate network would be considered high. In the next 2 seconds, the 37 yd/sec error would be reduced further to approximately a 14 yd/sec error (37% × 37).

If the *Tc* is 16 seconds, the 100 yd/sec error would be reduced to a 37 yd/sec error in 16 seconds, and the sensitivity of the network would be considered low. In the next 16 seconds, the 37 yd/sec error would be reduced further to approximately 14 yd/sec error (37% × 37). Thus the time constant can be used as an indication of the system sensitivity, or the speed with which it arrives at a solution accurate enough to compute adequate gun orders.

Functionally, the sensitivity network of Computer Mark 1A is composed of two separate parts: (1) control of the sensitivity of the range rate control network and (2) control of the sensitivity of the bearing and elevation rate control network.

25C9. Range rate control network

1. *General.* Control of the sensitivity of the range rate control network enables the computer range operator to use large direct range rate corrections (*jdR*) when the range rate errors are large, and small direct range rate corrections (*jdR*) when the range rate errors are small, by varying the time constant of the network and hence the sensitivity. Before discussing how this is accomplished, however, it is necessary to understand the operation of the network. Figure 25C7 shows the units employed in the range rate control network.

2. *Operation.* The director transmits to the computer range receiver a value of observed range (*R*) which is sent to the inner coarse and fine computer range dials (shown in the figure). The outer (ring) coarse and fine range dials are driven by a value of generated range (*cR*). If the computed range rate (*dR*) is correct, the *R* and *cR* dials will change (rotate) at the same rate. In addition, since all range lines in the computer are positioned by a value of generated range, *cR* must be exactly equal to *R* whenever *R* is correct.

Operation of the network is governed by the position of the range rate control switch, which has two positions: AUTO and MANUAL.

a. Auto position. Normal computer range operation is obtained with the range rate control switch positioned to AUTO. The *R* and *cR* dials continuously are kept matched and rotating together by the *jdR* follow-up and motor shown in figure 25C7. A special contact arrangement between the dials controls the motor which drives the difference between *R* and *cR* through a *range correction ratio changer* into the *cR* line. The linear correction to *cR*, shown in the figure, is called linear range correction, *jRc*.

Whenever either the director rangefinder operator or the radar range operator depresses his director rate control button (not shown in figure), the *jdR* clutch is energized (closed), and a value proportional to the difference between *R* and *cR* is also driven into the rate control mechanism as direct range rate correction, *jdR*.

b. Manual position. Whenever the range rate control switch is positioned to MANUAL, the computor range operator must perform the function of the *jdR* follow-up motor by rotating the range handcrank. With the range handcrank in the OUT position, the computer range operator matches the generated range dials with the observed range dials. In so doing, he introduces initial range (*jR*) into the computer. If the computer has been tracking a target, the tracking section has developed increments of generated range (Δ*cR*), which are combined with *jR* to produce generated range (*cR*). As shown in the figure, *cR* is used both in the computer prediction section and to position the *cR* dials.

With the range handcrank at the IN position, the computer range operator can still match the generated range dials with the observed range dials, though at a much slower rate, since the input must pass through the range correction ratio changer.

As shown in figure 25C7, whenever the computer range operator rotates the range handcrank in the IN position to keep the *cR* dial rotating at the same rate as the *R* dial, and at the same time pushes the computer range rate control manual push button, the *jdR* clutch is energized (closed), and a value proportional to the difference between *R* and *cR* is driven into the rate control mechanism as *jdR*.

3. *Sensitivity control.* The range correction ratio changer is a disc-type integrator whose function is to control the amount of direct range rate correction (*jdR*) going into the rate control mechanism for any given amount of linear range correction (*jRc*). The disc of the mechanism is turned by direct range rate correction (*jdR*). The carriage is positioned directly by the range time constant knob on the front of the computer. The roller drives linear range correction (*jRc*) into the *cR* line.

It should be remembered that the output of a disc-type integrator depends both on the input to the disc and on the position of the integrator carriage on the disc. With the carriage near the center of the disc, the roller output will be minimum. With the carriage at the periphery (edge) of the disc, the roller output will be maximum.

A sleeve on the range time constant knob is graduated from 0 to 16 seconds. As previously stated, the time constant represents the time in seconds required to reduce a given rate error to 37% of its initial value, and is a measure of the sensitivity of the network. The setting on the RTC knob determines the amount of direct range rate correction (*jdR*) introduced into the rate control mechanism for each unit of linear range correction (*jRc*) applied to generated range (*cR*).

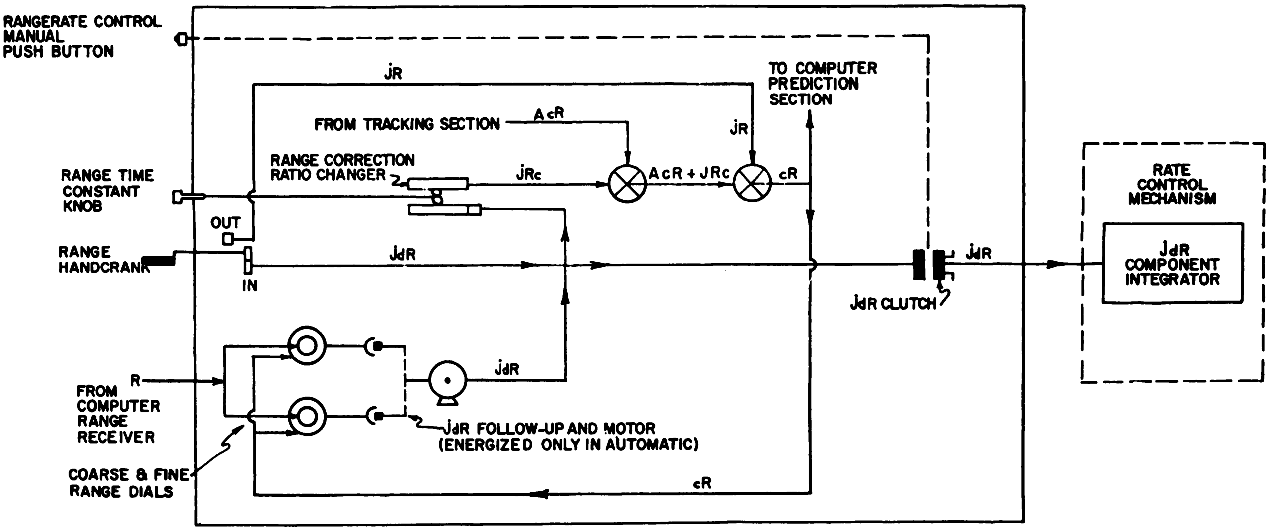

RANGERATE CONTROL MANUAL PUSH BUTTON
jR
TO COMPUTER PREDICTION SECTION
FROM TRACKING SECTION
AcR
jR
RANGE CORRECTION RATIO CHANGER
jRc
AcR + JRc
cR
RANGE TIME CONSTANT KNOB
OUT
RANGE HANDCRANK
JdR
IN
JdR
JdR CLUTCH
RATE CONTROL MECHANISM
JdR COMPONENT INTEGRATOR
R
FROM COMPUTER RANGE RECEIVER
JdR
JdR FOLLOW-UP AND MOTOR (ENERGIZED ONLY IN AUTOMATIC)
COARSE & FINE RANGE DIALS
cR

FIGURE 25C7.—Range rate control network.

Suppose generated range (*cR*) needs a correction (*jRc*) which requires ten turns of the integrator roller. If the range time constant knob is at the 1-second position, the integrator carriage is positioned near the center of the disc; hence relatively many turns of the disc (by the input *jdR*) are needed to turn the integrator roller the ten revolutions to produce the required amount of *jRc*. A relatively large *jdR*, therefore, is applied to the rate control mechanism (if the *jdR* clutch is energized) for the *jRc* needed to match the range dials.

If the range time constant knob is at the 16-second position, the integrator carriage is positioned near the periphery (edge) of the disc; hence relatively few turns of the disc (by the input *jdR*) are needed to turn the integrator roller the ten revolutions to produce the required amount of *jRc*. A relatively small *jdR*, therefore, is applied to the rate control mechanism (if the *jdR* clutch is energized) for the *jRc* needed to match the range dials.

By positioning the range time constant knob, the computer range operator controls the sensitivity of the range rate control network. By selecting a small RTC setting, a large value of *jdR* can be applied to the rate control mechanism. By selecting a large RTC setting, a small value of *jdR* can be applied to the rate control mechanism. In practice, the computer range operator should keep the setting of the range time constant knob as low as possible without causing instability in the computer solution.

25C10. Bearing and elevation rate control network

1. *General.* Figure 25C8 shows the units employed to control the sensitivity of the bearing and elevation rate control network. As shown in the figure, the function of the network is to convert the angular bearing and elevation rate corrections (*jBr* and *jE*) into linear bearing and elevation rate corrections (*jBc* and *jEc*). These linear corrections are applied to the component integrators of the rate control mechanism as explained in paragraph 25C7. The sensitivity of the network is controlled:

a. By network design to cause the magnitude of the linear output to vary with a value of range.

b. By operation of the sensitivity push button.

The ensuing discussion will explain both sensitivity control and operation of the network.

The value of the time constant (*Tc*) in seconds for the network is expressed by the following equation: $Tc = 2 \times R/R''$.

The constant 2 represents the basic time constant established by the change gears. As shown in figure 25C8, the change gears (labeled *Ke* and *Kb*) reduce the value of the angular rate corrections (*jBr* and *jE*) applied to the correction integrator. This reduction is reflected in the magnitude of the integrator outputs (*jBc* and *jEc*), and hence affects the sensitivity of the network at all ranges.

It is necessary to reduce the measured angular rate corrections (*jBr* and *jE*) applied to the network in order to prevent overcorrection of the solution by the rate control mechanism due to the tracking errors. Whenever the rate control mechanism is employed, the amount of handwheel motion by the director pointer and trainer in staying on target determines the magnitude of the angular rate corrections (*jBr* and *jE*).

These handwheel motions contain tracking errors due to inaccurate tracking of the target in bearing and elevation, lost motion in the mechanical parts of the system, and maladjustment of the power drives and radar. By employing change gears, the effect of

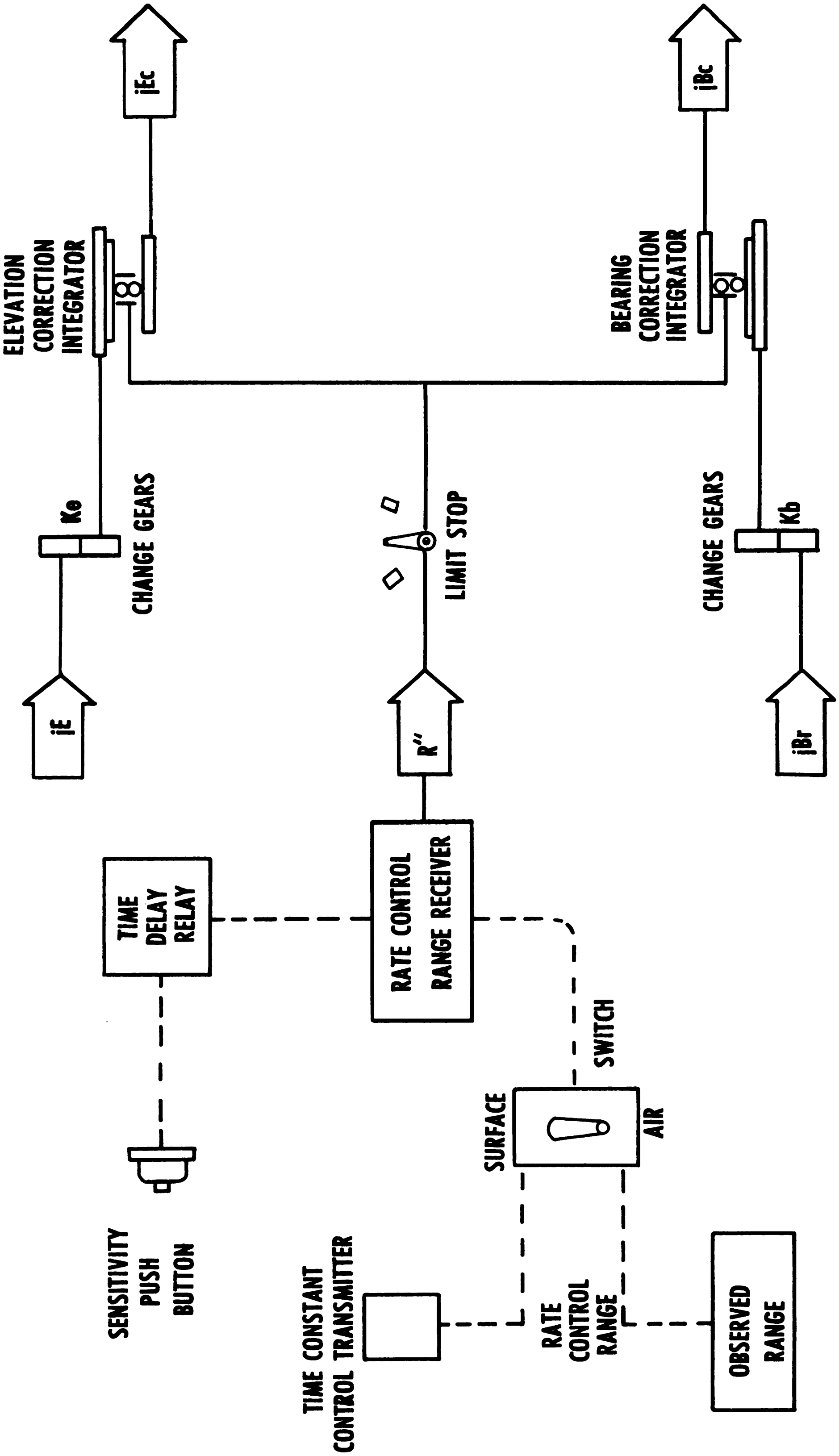


FIGURE 25C8.—Sensitivity control systems.

the tracking errors in overcorrecting the solution is reduced. Normally the change gears installed give the network a basic time constant of two seconds.

The bearing and elevation correction integrators are employed to multiply the angular corrections (jBr and jE) by a value of range (which is limited from 500 yards to 8,000 yards by the limit stop shown in figure 25C8). Thus the angular rate corrections are converted into linear rate corrections (jBc and jEc) required by the component integrators of the rate control mechanism. The value of range called rate control range (R''), positions each correction integrator carriage near the center of the disc for ranges of 500 yards, and near the periphery (edge) of the disc for ranges of 8,000 yards. In the former case ($R''=$ 500 yd), the output of each integrator will be minimum, and in the latter case ($R''=$8,000 yd), the output of each integrator will be maximum.

2. *Air targets.* For operation against air targets, the AIR-SURFACE switch is positioned at AIR. The range input from the rangefinder or radar activates the rate control range receiver shown in figure 25C8. In the latter unit, a single-speed synchro motor is used to receive the input value of observed range and to close contacts on a servo motor. This causes the value of range to drive through the limit stop to position the correction integrator carriages.

When observed range is between 500 yards and 8,000 yards, the limit stop will not function and the value of observed range will be equal to the value of rate control range ($R=R''$). Thus, since the ratio of R/R'' is unity, the time constant for the network becomes equal to the basic time constant, or 2 seconds.

When the observed range equals or exceeds 8,000 yards, the limit stop functions, and the value of rate control range (R'') applied to the two correction integrator carriages remains at 8,000 yards. Therefore, for all air targets at a range of 8,000 yards and beyond, the value of the linear rate corrections (jBc and jEc) applied to the component integrators is a maximum. As can be determined from the time constant equation ($Tc=2\times R/R''$), the time constant will increase uniformly as the range increases beyond 8,000 yards; hence the network sensitivity will commence to decrease uniformly beyond that range.

Figure 25C9 will clarify the preceding discussion. The figure assumes a target at 8,000 yards (position 1) and a target at twice the range, or 16,000 yards (position 2). The effect of the change gears in reducing the value of jE applied to the elevation correction integrator will be represented by a constant gear ratio, Q. The output of the elevation correction integrator for a target at position 1 is the correct linear equivalent of jE, since $jEc1=Q\times R''\times jE$ and $R=R''$. Furthermore, this represents the maximum output of the correction integrator, since R'' is limited to 8,000 yards by the limit stop. But at position 2, the correct linear equivalent of jE is $jEc2$, obtained by multiplying the product ($Q\times jE$) by a range of 16,000 yards ($jEc2=Q\times jE\times 16{,}000$).

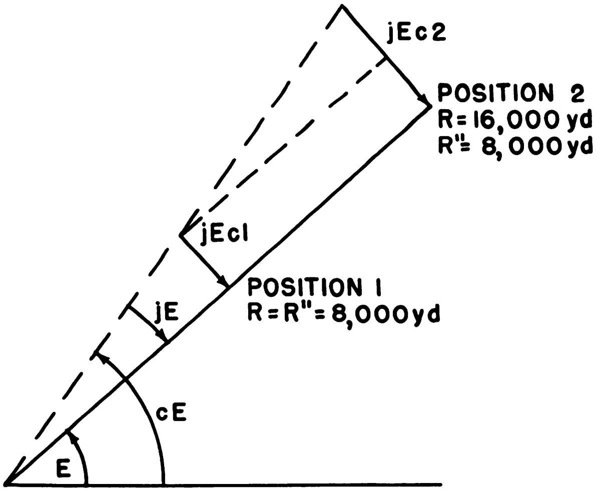


FIGURE 25C9.—Conversion of jE and jEc.

Since by design of the network $jEc1$ is applied to the component integrators at all ranges of 8,000 yards and beyond, it will take a longer time for the rate control mechanism to reduce the given angular rate error for a target at position 2 than at position 1. Note that for the ranges given in the figure $jEc2=2\times jEc1$, and that the range at position 2 is twice the range at position 1. Since at position 2 only one-half of the correct linear rate correction is being applied to the component integrators, it will take twice as long for the rate control mechanism to remove the entire jE correction for a target at position 2 as at position 1. This can be substantiated further by substituting the correct values of range in the network time constant equation ($Tc=2\times R/R''$):

$$\text{Position 1: } Tc=2\times\frac{8{,}000}{8{,}000}=2 \text{ seconds.}$$

$$\text{Position 2: } Tc=2\times\frac{16{,}000}{8{,}000}=4 \text{ seconds.}$$

For air targets below ranges of 8,000 yards, it may be necessary to lower the network time constant (increase the sensitivity) momentarily in order rapidly to remove large rate errors such as those caused by a radically maneuvering target. To enable the computer operator to lower the time constant temporarily, the *sensitivity push button* and the *time delay relay* (see fig. 25C8), are provided. Pressing the sensitivity push button causes the range servo motor of the rate control range receiver to drive to its upper limit (8,000-yard position). After the sensitivity push button is released, the time delay relay maintains this position for a predetermined period, usually about 2 seconds. For example, if a target is at a range of 5,000 yards, the network time constant is:

$$Tc=2\times\frac{5{,}000}{5{,}000}=2 \text{ seconds.}$$

If the sensitivity push button is pressed, the time constant becomes

$$Tc=2\times\frac{5{,}000}{8{,}000}=1.25 \text{ seconds.}$$

Thus the rate error will be reduced to 37% of its initial value in 1.25 seconds instead of 2 seconds.

3. *Surface targets.* For surface targets, the AIR-SURFACE switch is positioned at SURFACE. When so positioned, it disconnects the rate control range receiver from the rangefinder or radar, and connects it to the *time constant control transmitter.* The latter unit is a synchro transmitter used to transmit a predetermined value of range to the rate control range receiver. This value is usually set at 3,000 yards, since experience has proved that the system operates best at this range for surface targets. Thus, as determined by the time constant equation, the time constant will increase uniformly at all ranges for surface targets, since R'' is always 3,000 yards, unless the sensitivity push button is pressed.

In the latter case, R'' becomes 8,000 yards for approximately two seconds, as explained above. For the surface problem, pressing the sensitivity push button will reduce the time constant at all ranges, and hence increase the network sensitivity. The following examples will illustrate how the time constant is affected by the sensitivity push button for the surface problem. If the observed range is 8,000 yards, the time constant is:

$$Tc=2\times\frac{8{,}000}{3{,}000}=5.3 \text{ seconds.}$$

Pressing the sensitivity push button reduces the time constant to:

$$Tc=2\times\frac{8{,}000}{8{,}000}=2 \text{ seconds.}$$

For a range of 5,000 yards, the time constant is:

$$Tc=2\times\frac{5{,}000}{3{,}000}=3.33 \text{ seconds.}$$

Pressing the sensitivity push button reduces the time constant to:

$$Tc=2\times\frac{5{,}000}{8{,}000}=1.25 \text{ seconds.}$$

25C11. General description

Computer Mark 1A is built in four sections for ease of handling and assembling. These are: *control* section, *indicator* section, *computer* section, and *corrector* section. The first two are mounted on top of the second two in the order given. Figure 25C2 shows these four sections. The side nearest the stable element is the rear of the computer.

The control section contains the mechanisms for computing and controlling rates, and carries most of the knobs, cranks, and dials. The computer section (below the control section) contains the mechanisms that calculate the ballistics. The indicator section shows on dials and counters the end results of the ballistic calculations: sight angle (Vs), sight deflection (Ds), fuze order (F), and advance range ($R2$). Below the indicator unit, the corrector unit computes and indicates gun train order, gun elevation order, and parallaxes. Figure 25C1 shows many of these items, plus additional ones, some of which will be discussed later. Frequent reference to this figure in the following discussion will help the student to grasp the overall picture of the computer.

Many of the knobs and cranks have more than one position. Locking pins are provided to hold the cranks in the position desired. Some knobs have crank handles attached to permit rapid turning.

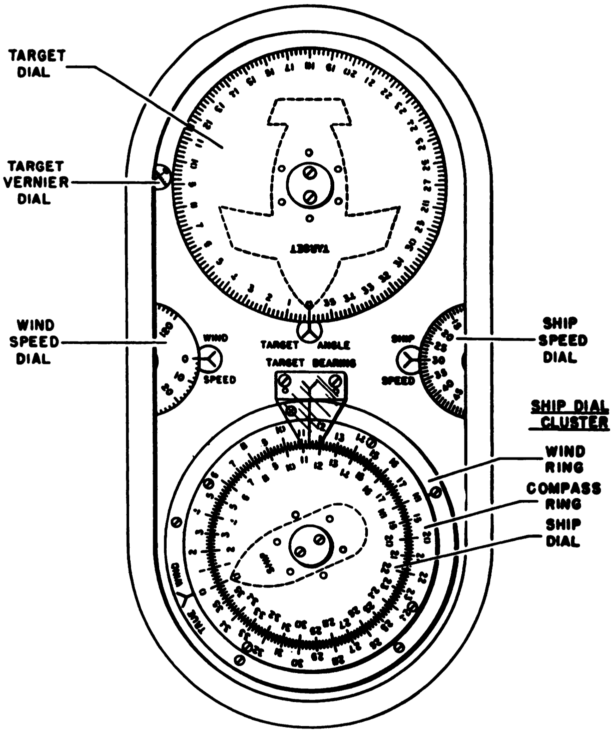


FIGURE 25C10.—Target and ship dial group.

25C12. Target and own-ship dial group

Refer to figure 25C10 when studying this article. This group is located on the control unit at the rear center (see fig. 25C1). The directions of wind, own-ship, and target motions and the speeds of wind and own ship are indicated. Inscribed on the target dial, at the rear, are the outline of a plane and a compass rose. The own-ship dial group, at the front, has three concentric dials. On the inner dial are inscribed the outline of a ship and a compass rose. The intermediate ring dial has only a compass rose, while the outer ring dial has only an index mark. Between the target dial and the own-ship dial group is a pair of fixed indexes (in line with one another) representing the horizontal projection of the line of sight.

The target dial indicates only target angle (*A*) against the fixed index. The inner or ship dial of the front group reads relative target bearing (*Br*) against the fixed index. On the compass ring of the intermediate ring dial, own ship's course (*Co*) is read against the bow of the ship outline of the inner dial. Also on the intermediate ring, true bearing (*B*) is read against the fixed index. The value of true direction of true wind (*Bw*) is determined by reading the intermediate-dial compass rose against the index of the outer ring. The student is reminded that *Bw* is the direction *from* which the true wind is blowing.

Normally *Co* and *So* are received by synchro transmission from the gyro compass and the pitometer log respectively. Own ship's speed is indicated in knots on a dial to the right of and between the target dial and own-ship dial group. Both *Co* and *So* can be put in manually by the own-ship course knob and the own-ship speed knob respectively. These knobs have two positions, IN and OUT. In the OUT position, the values of *Co* and *So* are received electrically, while, with the knobs IN, *Co* and *So* must be introduced into the computer manually.

Bw and *Sw* are introduced manually by knob only. The instrument continuously computes wind angle between the wind direction and the line of fire. Thus the setting of *Bw* is changed only when the wind direction changes. See figure 25C12.

Introducing target angle (*A*) into the computer enables the computer to solve for the value of true target course (*Ct*). This true course will be corrected continuously as in the surface rangekeeper. Target angle can be introduced into the computer automatically or manually.

In normal computer operation (automatic rate control), *A* is slewed to the proper 90° quadrant when the computer time motor is started; thereafter the exact value of *A* is determined and kept corrected by the rate control mechanism.

In manual computer operation (manual rate control), *A* is estimated by the director crew, phoned to the plotting room, and introduced manually into the computer; thereafter *A* is changed as necessary to obtain a correct solution.

The target angle (*A*) knob has attached to it a two-position shift lever labeled HAND and AUTO. To introduce *A* into the computer manually, the shift lever must be thrown to HAND. To permit changes of *A* by the rate control mechanism, the shift lever must be thrown to AUTO. In addition, for the rate control mechanism to function, similar levers on the target-speed (*Sh*) knob and rate-of-climb (*dH*) must be thrown to AUTO.

25C13. Target-speed and time dial group

This group, under a single round window, is located at the right front of the control unit (fig. 25C2). Displayed are: *dH* in knots on a dial, *Sh* in knots on a counter, target-speed diving in knots on a dial, and time on two dials (fig. 25C11).

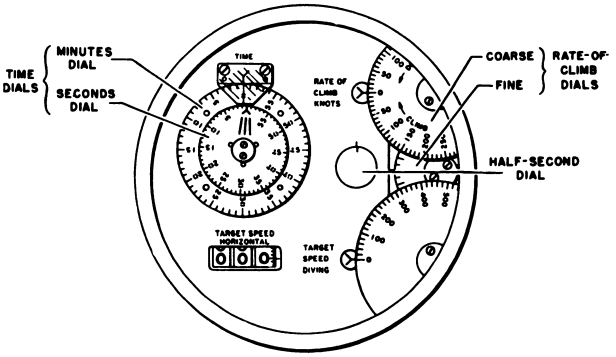


FIGURE 25C11.—Target-speed dial group.

The rate-of-climb (*dH*) dial is at the right rear of the group. *dH* can be introduced manually, but normally is controlled by the rate control mechanism as described in article 25C7. The *dH* knob shift lever is thrown to HAND for manual operation and to AUTO for control of *dH* by the rate control mechanism.

At the left front of the window is the *Sh* counter which shows horizontal ground speed of the target in knots, from 0 to 800 knots. As with rate of climb, *Sh* can be introduced manually, but normally is controlled by the rate control mechanism as described in article 25C7. The *Sh* knob shift lever is thrown to HAND for manual operation and to AUTO for control of *Sh* by the rate control mechanism.

For tracking high-speed surface targets, a low elevation switch keeps *dH* equal to zero whenever *E* becomes less than 2 degrees. In manual computer operation (manual rate control) *Sh* and *dH* are estimated by the director crew, phoned to the plotting room, and introduced manually into the computer;

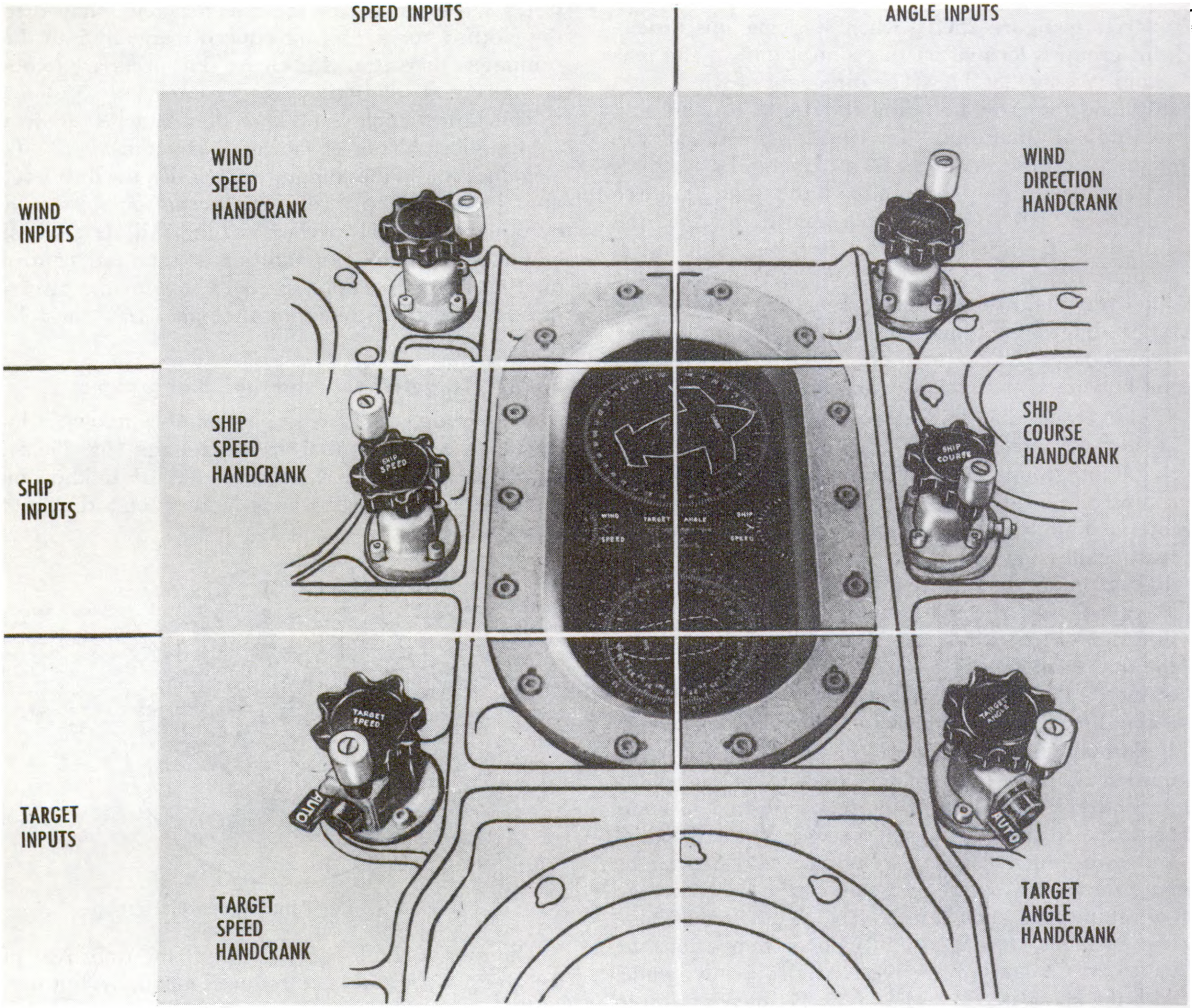


FIGURE 25C12.—Target, own-ship, and wind knobs.

thereafter *Sh* and *dH* are changed as necessary to obtain a correct solution.

The right front dial of the group shows negative range rate or diving speed. It is used only for dive attacks. In such attacks the target moves virtually along the line of sight, making its total relative motion equal to negative *dR*. This rate is set on the dial manually by a special knob: the range-rate/diving-speed knob. See figure 25C13. This knob has a two-position lever like the *A* and *Sh* knobs. The lever is shifted to HAND (for dive attacks only) for manual operation. It is left at AUTO at all other times, so the rate control mechanism will be free to function as described in article 25C7.

The time dials located at the left rear of the window show time in minutes and seconds. The ring dial indicates minutes, while the inner dial reads seconds. Driven by the computer time motor, these dials are used in conducting maintenance tests. They can be set manually by the time crank. Pushing the crank IN causes the minute ring dial to return to zero automatically. Then the crank, still IN, is turned to set the inner, second dial against a fixed index. With the time motor not functioning, the time crank in the OUT position can be used to turn all shafts transmitting time in the computer. A small dial near the center of the window is designed to rotate twice each second. Checking this dial with a clock or watch, the operator can rotate the time crank by hand to supply the computer with time input if the time motor fails.

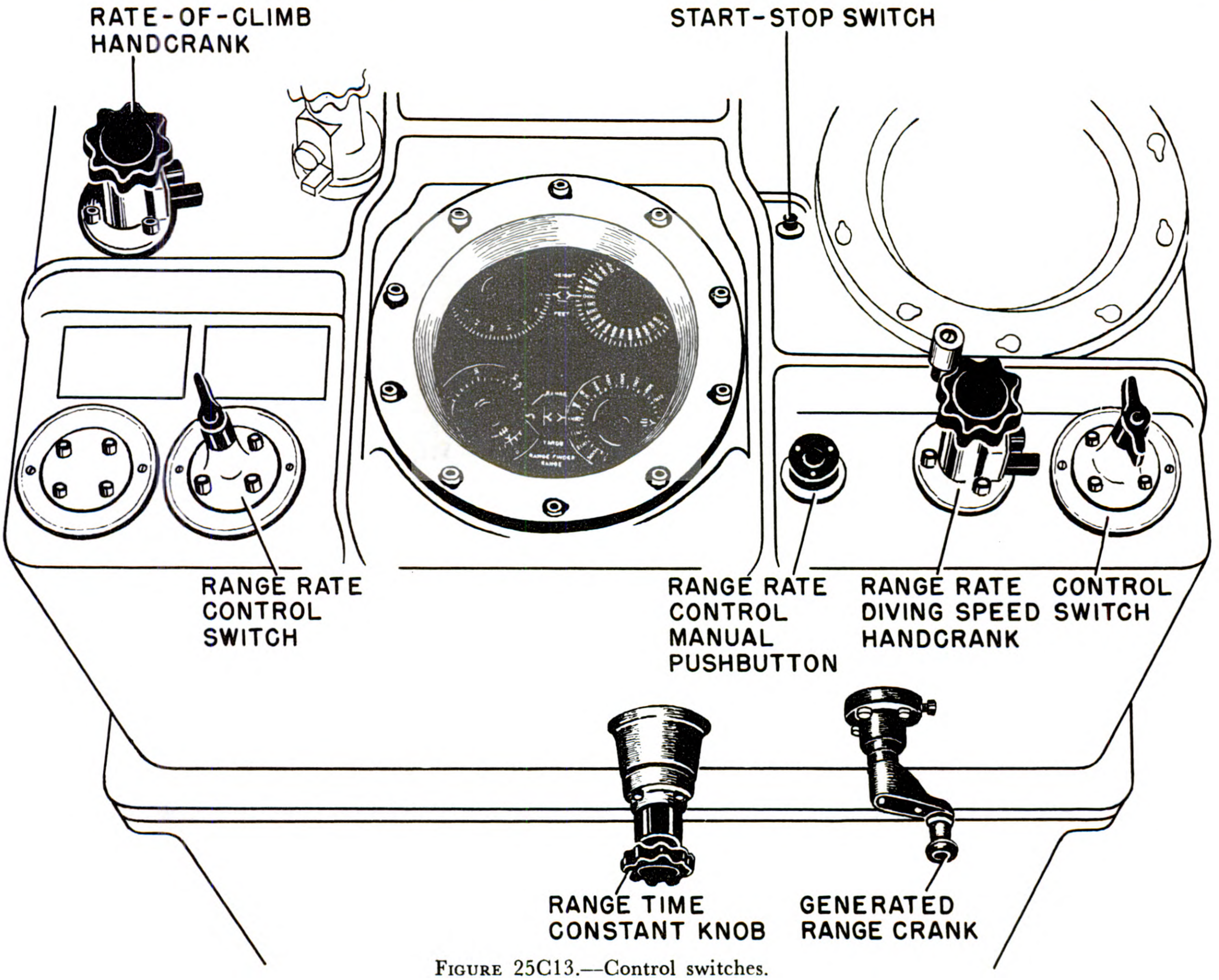


FIGURE 25C13.—Control switches.

25C14. Control switches

There are two switches located at the computer range operator's station on the front top edge of the control section as shown in figure 25C13. These switches are the *control switch* and the *range rate control switch*. They are used to select the method of rate controlling and computer operation.

The control switch has three positions: NORMAL, TEST, and LOCAL. Positioning the switch causes changes in the computer electrical circuits required by the methods of rate control for bearing and elevation and for operation of the computer without director inputs. With the control switch on NORMAL, bearing and elevation rate corrections are introduced into the rate control mechanism by the director trainer and pointer turning their handwheels with the rate control keys closed. This is the method of rate controlling called *automatic rate control*—discussed in paragraph 25C6(3)(a)—and is employed against all air targets as well as surface targets at speeds of 15 knots or greater.

With the control switch in the TEST position, manual rate control only is possible. Changes in *A*, *Sh*, and *dH* (for air targets) are made manually by computer operators until the generated bearing and elevation dials are rotating at the same rate as the observed dials. This method of rate control must be used for targets at speeds below 15 knots as explained in paragraph 25C6(3)(b). The rate control mechanism does not function with the switch at TEST.

With the control switch at LOCAL, director inputs are prevented from entering the computer, and the computer solution is based upon its own generated value of relative target bearing. This allows the computer to be used for indirect fire against a surface target when the target is not visible from the director. Range and target bearing are obtained from a source other than the director, such as combat information center, and entered manually into the computer.

The rate control mechanism does not function with the switch at LOCAL. The range rate control switch has two positions: AUTO and MANUAL. Positioning the switch causes changes in the computer electrical circuits required by the methods for rate controlling in range and described in article 25C9. With the switch at AUTO, either the rangefinder operator or the radar operator in the director initiates the rate control corrections in the computer. With the switch at MANUAL, rate controlling in range is performed at the computer by the computer (range) operator. The rate control mechanism will function for either switch position unless the rate control mechanism is made inoperative by positioning the control switch at TEST or LOCAL.

While the control switch and the range rate control switch are not tied together, neither will permit the rate control mechanism to function properly unless the four shift levers are all at AUTO. These shift levers are on the *A* knob, the *dH* knob, the *Sh* knob, and the range-rate/diving-speed knob.

Normal operation of the computer employs the automatic rate control mechanism, and is obtained by the following switch positions:

Control switch	NORMAL
Range rate control switch	AUTO or MANUAL
A, Sh, dH, and diving-speed knobs.	AUTO

Manual operation of the computer requires that the computer crew employ manual rate control methods, and requires the following switch positions:

Control switch	TEST
Range rate control switch	MANUAL
A, Sh, and *dH* knobs	HAND
Diving speed	AUTO

Local operation of the computer requires the following switch positions:

Control switch	LOCAL
Range rate control switch	MANUAL
A, Sh, and *dH* knobs	HAND
Diving speed	AUTO

25C15. Bearing and elevation dial groups

These groups are shown in the figures 25C14 and 25C15. The bearing group is located at the right rear of the control unit (fig. 25C2). It consists of two pairs of dials, each having an inner dial and a ring dial. The two ring dials show observed relative target bearing (*Br*). The coarse ring dial is graduated through 360°, while the fine ring dial is graduated through 10° of *Br*. The inner dial of the fine dial group has 10 equally spaced scribe marks only. This dial is driven by generated relative target bearing (*cBr*). When the control switch is at NORMAL or LOCAL, the *cBr* dial is driven by the bearing follow-up motors, which cause it to rotate automatically at the same rate as the fine *Br* dial. When the control switch is at TEST, these dials rotate together only when the computer solution is correct. Any difference in the speeds of rotation of these dials indicates an incorrect solution and the need for a correction to the computed bearing rate. The generated bearing crank is located close to the bearing dial group (fig. 25C2). Turning this crank changes the values of *cBr*.

Located at the left rear of the control unit is the elevation dial group (fig. 25C2). This group is very similar to the bearing group except for the graduations and values used to drive the dials. The two ring dials (fig. 25C14) show observed target elevation (*E*). Within the fine-ring *E* dial is the inner dial inscribed with 10 equally spaced scribe marks only. This dial is driven by the values of generated target elevation (*cE*). The inner dial of the coarse-ring *E* dial is blank and does not rotate. When the control switch is at NORMAL, the *cE* dial is driven by an elevation follow-up motor which causes it to rotate automatically at the same rate as the fine *E* dial. When the control switch is at LOCAL, the elevation dials will show 0° target elevation, since the local position is used for surface fire only and there are no director inputs.

With the control switch at TEST, the fine *E* dial and the *cE* dial rotate together only when the solution is correct. Any difference in the speeds of rotation of these dials indicates an incorrect solution and the need for a correction to the computed elevation rate. The generated-elevation crank is located close to the elevation dial group (see fig. 25C2). Turning this crank changes the value of *cE*.

The value of observed target elevation shown on the

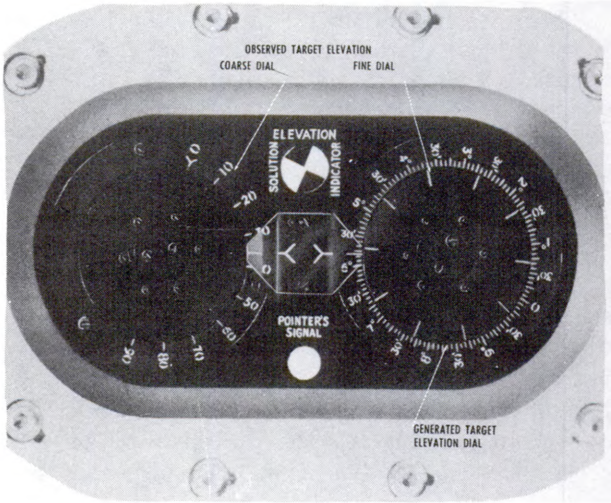


FIGURE 25C14.—Elevation dials.

dials and used in the computer can be varied by use of the synchronize-elevation knob. Use of this knob will be described in article 25C17.

Both bearing and elevation dial groups have two small indicators located at the edges about halfway between the ring dials. See figures 25C14 and 25C15. One of these indicators shows red when the rate control key in the director is closed. The other indicator is a dial having two black and two white quadrants. This indicator rotates when the director trainer (pointer) turns his handwheels in automatic rate control. It is called a solution indicator. A red signal and a moving solution indicator show that rate corrections are entering the computer's rate control mechanism. As explained earlier, this statement is true only if the four shift levers are thrown to AUTO.

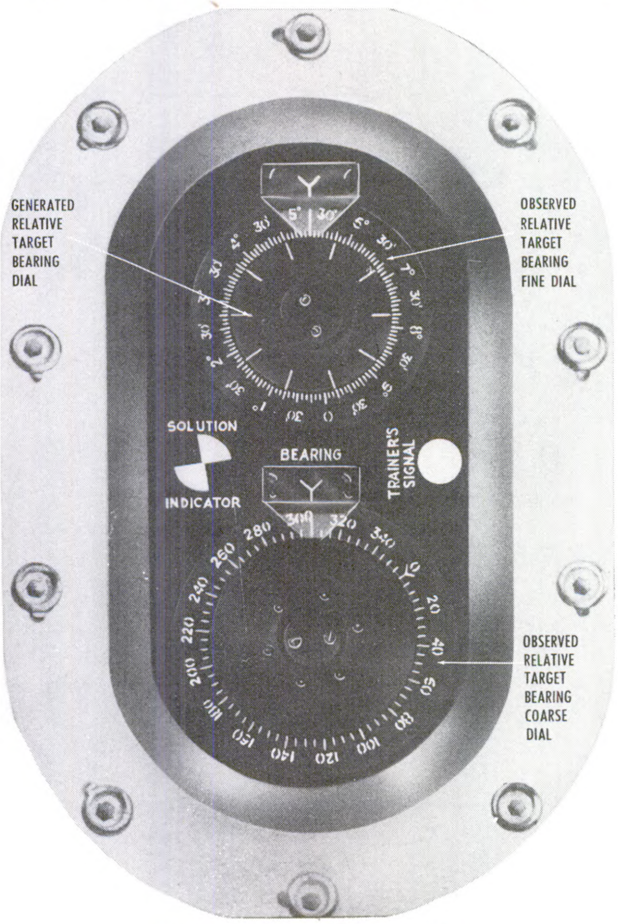

GENERATED RELATIVE TARGET BEARING DIAL
OBSERVED RELATIVE TARGET BEARING FINE DIAL
SOLUTION
INDICATOR
BEARING
TRAINER'S SIGNAL
OBSERVED RELATIVE TARGET BEARING COARSE DIAL

FIGURE 25C15.—Bearing dials.

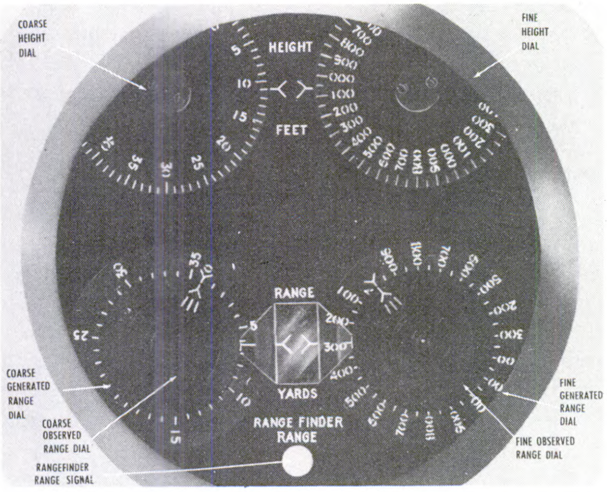


FIGURE 25C16.—Range and height dials.

25C16. Range and height dial group

This dial group is shown in figure 25C16. It is located at the front center of the control unit (see fig. 25C2). It consists of two sets of dials—one for range and one for height. The two dials at the rear of this group show coarse and fine values of generated target height (cH). This quantity is not used in normal operation of the computer.

The range dials consist of two pairs of ring and inner dials. From left to right, the ring dials indicate coarse and fine values of generated present range (cR). Within each ring dial is a dial inscribed with a pointer only. From left to right, these dials are driven by coarse and fine values of observed present range (R). For proper operation of the computer, observed and generated present ranges must be equal, because the instrument uses cR for its calculations. When the range rate control switch is at AUTO, the range follow-up motor drives the cR dial to keep it matched with and rotating at the same rate as the R dial. When the dials are matched, the zero marks on the ring dials (cR) are opposite the pointers on the inner dials (R) as shown in figure 25C16. When so matched, the value of cR equals the value of R and can be read at the fixed indexes.

When the range rate control switch is at MANUAL, the range follow-up motor is deenergized, and the computer range operator, using the generated range handcrank, must match the cR dials with the R dials, thereby introducing the correct value of cR into the computer. If the computed value of range rate (dR) is correct, the R and cR dials will stay matched and rotate at the same speeds. If the computed value of range rate (dR) is not correct, the cR and R dials will not rotate at the same speeds, and consequently the dials will not remain matched. The computer range operator, then, must rematch the range dials and at the same time introduce range rate corrections into the rate control mechanism. This is accomplished by turning the generated range handcrank and depressing the computer range rate control manual push button as explained in article 25C9.

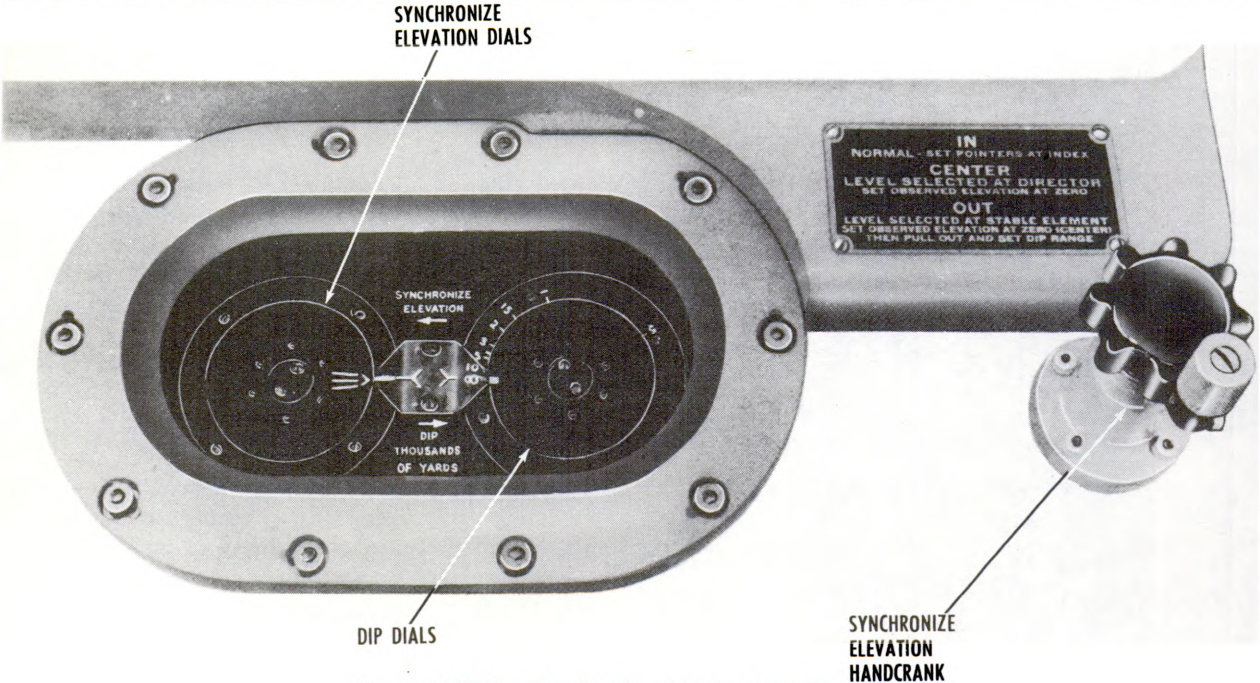

SYNCHRONIZE ELEVATION DIALS
IN
NORMAL - SET POINTERS AT INDEX
CENTER
LEVEL SELECTED AT DIRECTOR
SET OBSERVED ELEVATION AT ZERO
OUT
LEVEL SELECTED AT STABLE ELEMENT
SET OBSERVED ELEVATION AT ZERO (CENTER)
THEN PULL OUT AND SET DIP RANGE
SYNCHRONIZE ELEVATION
DIP THOUSANDS OF YARDS
DIP DIALS
SYNCHRONIZE ELEVATION HANDCRANK

FIGURE 25C17.—Synchronize-elevation and dip dials.

The generated range crank has two positions—OUT and IN. At the OUT position, the crank introduces and corrects *cR* by turning the *cR* dials, but does not affect range rate. When the crank is IN, it accomplishes the same thing plus introducing range rate corrections if the range rate control manual push button is depressed.

The computer is limited mechanically to a maximum tracking range of 35,000 yards. Accordingly, the course *cR* ring dial is graduated only to 35,000 yards. When the computer range limit is reached, the *cR* ring dial stops, but the pointer on the inner *R* dial continues to turn. This indicates to the operator that the actual range is beyond the computer limit, and it gives some idea of what the target is doing.

25C17. Synchronize-elevation and dip dials

This dial group and the associated knob are shown in figure 25C17. They are located on the indicator section just below the star-shell computer (see fig. 25C2). The function of the synchronize-elevation mechanism is to interrupt the computer elevation shafting in order to permit the Computer Mark 1A to be used for methods of fire which can be employed against surface targets, but which usually are not practical against air targets. The ensuing discussion will explain the use of the synchronize-elevation mechanism in each of its three positions: IN, CENTER, and OUT.

1. *In position.* With the synchronize-elevation knob in the IN position, the value of *E* used in the computing section of the computer is adjusted to the value of *E* obtained by combining *L* with *Eb* being measured by the director. This is done by matching the synchronize-elevation dials against the index (see fig. 25C17), which allows elevation $(Eb-L)$ to drive through the differential (*D*–12) unchanged (see fig. 25C18). The synchronize-elevation knob is always placed in the IN position and the synchronize-elevation dial matched, except for special types of surface fire.

Figure 25C18 shows the operation of the synchronize-elevation knob in the IN position. The knob is turned against brake pressure until the synchronize-elevation dials are matched. This introduces zero difference between right and left *E* shafts of differential *B*-12, and the friction brake prevents further turning of the shaft or synchronize-elevation dial. The output of differential *D*-11 then passes through differential *D*-12 unchanged, and is used in the generating and prediction mechanism to compute *Vs* as shown in figure 25C18.

2. *Center position.* In certain special types of surface fire the quantity *Eb* minus *L* is not introduced into the computing mechanism. For example, using selected elevation aiming, the director sights do not continuously remain on the target, but are fixed in relation to the deck. When the line of sight is off target in elevation, the combination of fixed *Eb* and changing *L* produces inaccurate values *E* which must not be allowed to enter the generating and prediction mechanism.

Placing the synchronize-elevation knob in the CENTER position accomplishes two things. First, the

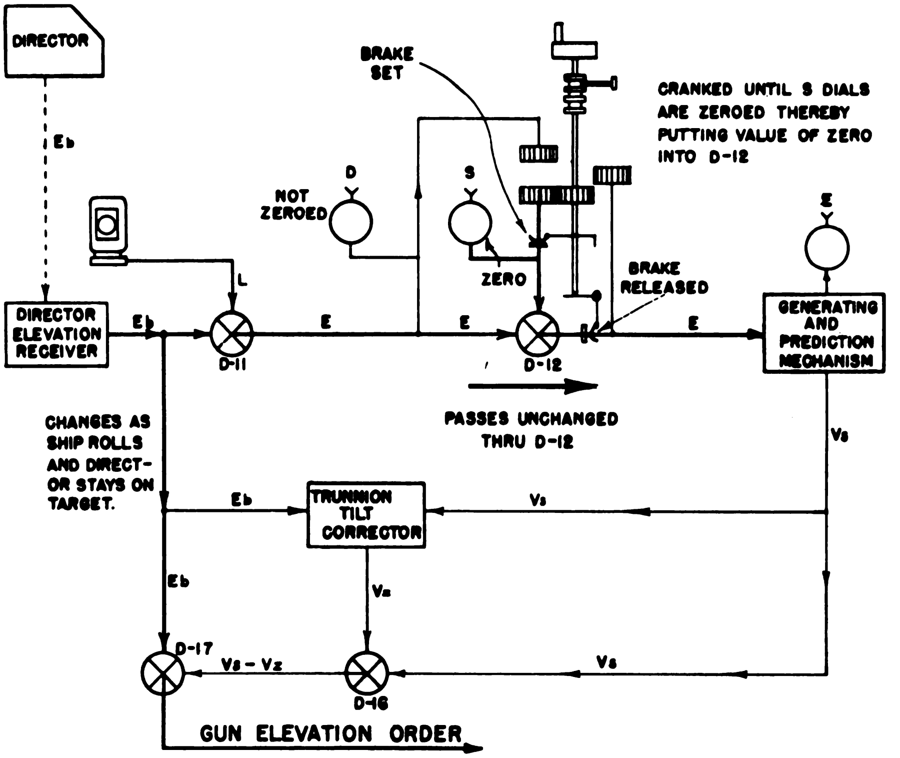

DIRECTOR
Eb
DIRECTOR ELEVATION RECEIVER
Eb
L
D-11
E
BRAKE SET
D
NOT ZEROED
S
ZERO
CRANKED UNTIL S DIALS ARE ZEROED THEREBY PUTTING VALUE OF ZERO INTO D-12
E
D-12
BRAKE RELEASED
E
E
GENERATING AND PREDICTION MECHANISM
PASSES UNCHANGED THRU D-12
CHANGES AS SHIP ROLLS AND DIRECTOR STAYS ON TARGET.
Eb
TRUNNION TILT CORRECTOR
Vs
Vs
Vz
Eb
D-17
Vs - Vz
D-16
Vs
GUN ELEVATION ORDER

FIGURE 25C18.—Schematic of synchronize-elevation with knob at IN.

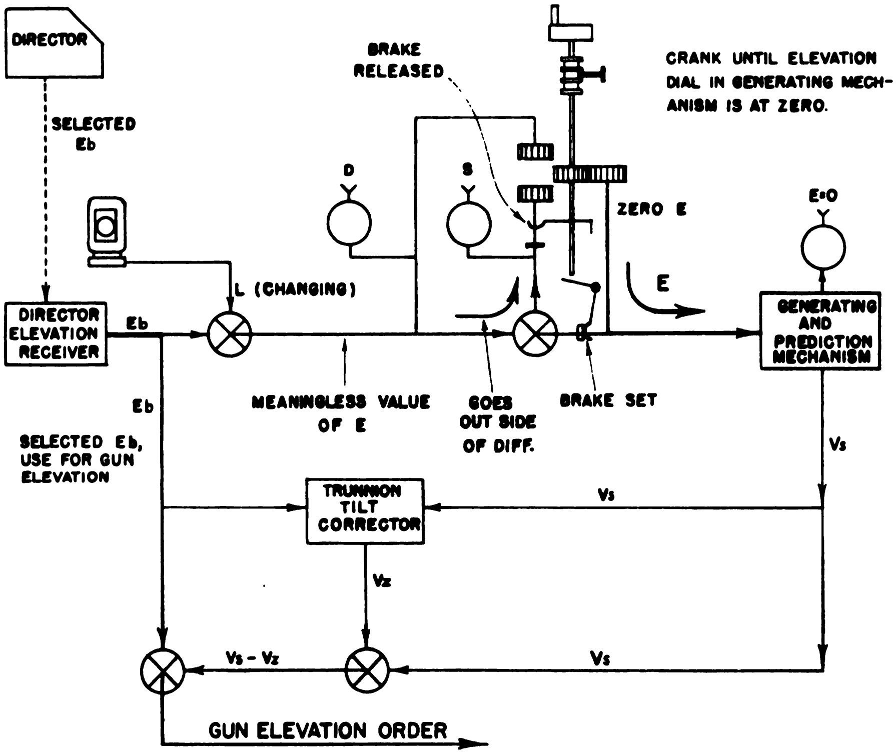


FIGURE 25C19.—Schematic of synchronize-elevation with knob at CENTER.

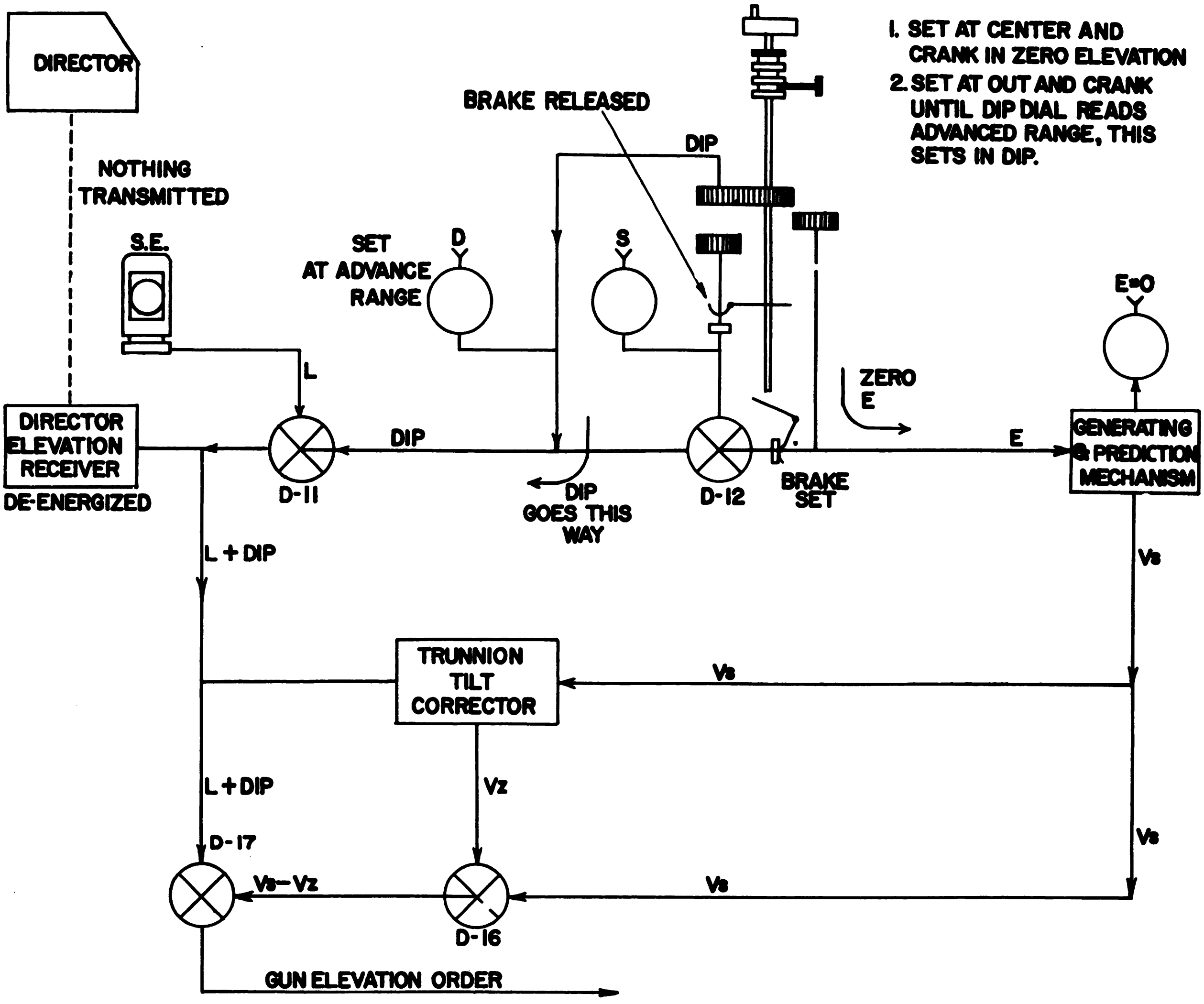


FIGURE 25C20.—Schematic of synchronize-elevation with knob at OUT.

inaccurate value of *E* is kept out of the generating and prediction mechanism by interrupting its transmission through the elevation shafting to the generating and prediction mechanism at differential *D*-12. Secondly, the elevation shafting leading out of differential *D*-12 and into the computing section is positioned by turning the synchronize-elevation knob. The shaft is always positioned at zero elevation, because the actual surface target elevation is close to that value. This value of *E* is used in the computer only for the computation of *Vs*.

Figure 25C19 illustrates the elevation lines when a selected *Eb* is used. Note that the meaningless value of *E* is prevented from entering the computing section by the friction brake on the *E* shafting to the right of differential D-12. Instead, the inaccurate value of *E* drives out the other side of differential D-12 and merely rotates the synchronize-elevation dials, which have no meaning in this case. The synchronize-elevation knob is geared to the *E* shaft of the computing mechanism, and is turned against brake pressure until the computer elevation dials (fig. 25C14) read zero. The selected value of *Eb* is combined in differential *D*-17 with *Vs* and *Vz* to give a fixed gun elevation order which is correct only at the instant the pointer's crosshair is on the target.

3. *OUT position.* The synchronize-elevation knob is placed in the OUT position when no value of *Eb* is received from the director. This is always the case during indirect fire, such as the bombardment of a hidden target. It is possible to fire without the aid of the *Eb* input by correctly positioning the *Eb* shafting at the computer with a substitute value of *Eb*.

The elevation shafting into the generating and prediction mechanism and to the elevation dials is placed at the zero value of elevation by turning the synchronize-elevation knob in the CENTER position as described above. The knob is then placed in the OUT position, which cuts out the input of *Eb* from the director. The value of *dip angle* is then set on the *Eb* shafting by matching the dip dial reading to *R*2, which the operator reads on the *R*2 counter. See figure 25C17.

Since the computation of gun elevation order is based on the angle *Eb,* a substitute value of *Eb* must be provided when the director is not used. This substitute value of *Eb* must closely approximate the value ordinarily supplied by the director. The substitute value of *Eb* is composed of *L* from the stable element, plus dip.

As shown in figure 25C21, dip to the target is the angle between the horizontal and a line of sight to the waterline of a surface target. This should not be confused with dip to the horizon. Dip is a function of range.

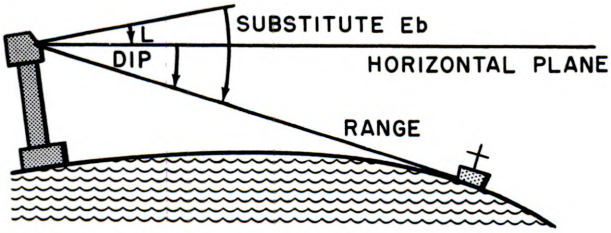


Figure 25C21.—Dip.

The graduations on the dip dial are spaced so that, when the index on the inner dial is under the fixed index and the value of range is at the fixed index, the dip-dial shafting is positioned at the corresponding value of dip. The dial is usually set to *R*2, because of the convenient location of the *R*2 counter to the dip dial and knob.

Figure 25C20 illustrates the elevation lines when the director is not furnishing *Eb*. First the *E* shafting into the generating and prediction mechanism is set to zero by turning the synchronize-elevation knob in the CENTER position as previously described. Then, with the knob in the OUT position, the dip dial is set according to the value of *R*2. This positions the shafting between differentials *D*-11 and *D*-12 at the value of dip angle. Note that this setting does not drive into the generating and predication mechanism, because the brake to the right of differential *D*-12 is set. *L* is combined with dip in differential *D*-11 to position the *Eb* shafting correctly as a substitute value of *Eb* which very closely approximates the corresponding observed value.

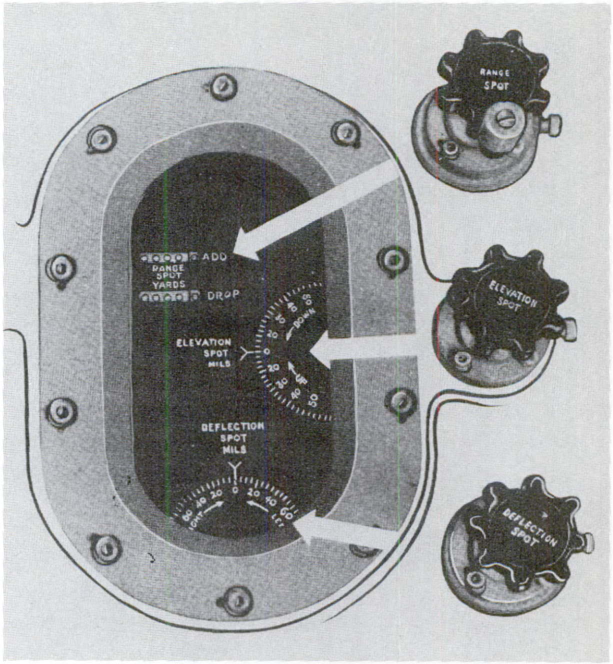


Figure 25C22.—Spot indicators.

Finally, when it is desired to return to normal, continuous-aim fire, the synchronize-elevation knob is returned to the IN position. This releases the brake to the right of differential *D*-12. In this position it is turned to align the synchronize-elevation dials with their fixed index, and in so doing realigns the *E* shafts on both sides of differential *D*-12 to make *E* the same on both sides. This again allows the correct value of *Eb,* as measured by the director, minus level (*L*), to drive through differential *D*-12 to the generating and prediction mechanism unchanged.

25C18. Spot indicators

Figure 25C22 shows the three spot indicators and their associated knobs. The entire group is located at the right of the indicator unit, as shown in figure 25C1, when viewed by a man facing the indicator unit. Elevation and deflection spots are shown on dials against fixed indexes from minus 180 mils to plus 180 mils. Range spots are shown on two counters. One counter indicates ADD spots to a maximum of 1,800 yards. The other counter reads DROP spots to a limit of 12,000 yards. The large DROP limit is provided for control of main-battery guns. Spots are received from the director and are normally applied electrically in the computer. However, spot knobs are available for manual settings. For electrical (automatic) reception, the knobs must be locked OUT, while they must be locked IN for manual operation.

The three spot receivers can get out of synchroniza-

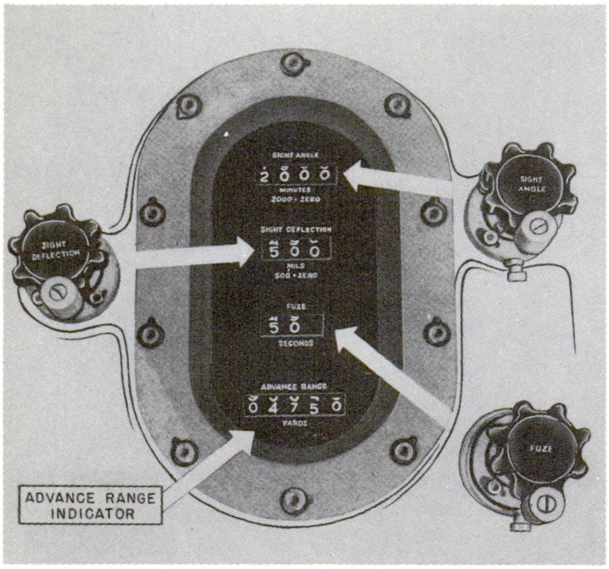


FIGURE 25C23.—Sight deflection, sight angle, fuze-setting order, and advance range indicators.

tion with their incoming signals. To prevent this, check to see that the dials and counters indicate proper values before shifting from manual to automatic operation.

25C19. Sight deflection, sight angle, fuze-setting order, and advance range indicators

This group of indicators and their associated dials are shown in figure 25C23. The group is located at the left rear of the indicator unit, next to the spot indicators, as shown in figure 25C1. This group includes four sets of counters that show the computed values of sight angle, sight deflection, fuze-setting order, and advance range. Sight angle is shown in minutes of arc, with 2,000 as the zero value. Sight deflection in mils has 500 as the zero value. Fuze-setting order is indicated in seconds of time, while advance range is shown in yards. All but advance range ($R2$) are normally sent to the guns electrically as computed by the instrument. However, there are three knobs for manual setting of the sight angle, sight deflection, and fuze orders. Manual operation is used with arbitrary values in connection with the control of main-battery guns, and in shore bombardment. Advance range is transmitted only to the star-shell computer. The indicated value of $R2$ is used with the dip dials, as described in article 25C17, and for checking purposes.

25C20. Other knobs, dials, and switches

Figure 25C1 shows the location and appearance of some of the knobs, dials, and switches mentioned in this article:

1. *Initial velocity dial(s) and knob(s).* Depending upon the modification of Computer Mark 1A, one or two I.V. knobs and dials are installed to permit setting manually the existing average initial velocity of the battery. The dials are graduated in feet per second between correct I.V. limits for the guns controlled by the computer. For the computer designed to control 5″/38 gun mounts, I.V. settings can be made between 2,350 fs and 2,600 fs. When two dials and knobs are installed, the same setting accounts for I.V. loss due to erosion, variations due to powder temperature, and compensation for air-density variations.

2. *Dead-time dial and knob.* The dead-time dial shows dead time (Tg), the time in seconds between setting of the fuze and firing of the projectile. The dial is graduated from 0 to 6 seconds, but varies with the average loading interval of the gun crews.

3. *Power switch.* The power switch energizes all the servo receivers which drive the various quantities into the computer mechanisms.

4. *Time push button and director trainer's rate control key.* With the power switch ON, the computer time motor circuit is energized up to a switch called the time motor switch. This latter switch is located inside the computer and is controlled by the time push button and the director trainer's rate control key as explained below. The time push button is located on top of the computer, to the left of the time dials.

With the power switch ON and the control switch at NORMAL, *either* closing the director trainer's rate control key or depressing the time push button starts the time motor. Once the time motor has been started, however, it can be stopped only by depressing the time push button. Thus, in normal operation employing automatic rate control, the computer will start tracking when the director trainer is on target and closes his rate control key. At the end of the tracking run, the computer range operator depresses the time push button to stop the time motor.

With the power switch ON and the control switch at either TEST or LOCAL, the time motor can be started and stopped only by alternately depressing the time push button. Thus, when employing manual rate control or local computer operation, the computer range operator must start and stop computer tracking.

5. *Air surface selector switch, sensitivity push button, range time constant knob.* Figure 25C1 shows these controls, which were discussed in articles 25C9 and 25C10.

6. *Other dials.* On the sides of the corrector section are a number of dials used for test purposes. These dials show the following values:

Gun train order ($B'gr$).

Gun elevation order ($E'g$).

Unit train parallax (Ph).
Unit elevation parallax (Pv), (for aircraft carriers only).
Level (L).
Crosslevel (Zd).
Elevation trunnion-tilt correction (Vz).
Deck deflection (Dd).

25C21. Star-shell computer

The Star-Shell Computer Mark 1 Mod 0 is designed to control dual-purpose guns for star-shell fire. The star-shell computer will control the illumination of a target which has been detected and for which gun orders are being computed by the Computer Mark 1A. Whereas the Computer Mark 1A computes gun orders to hit a given target, the star-shell computer utilizes those gun orders to calculate another set of gun orders to illuminate that same target. The instrument is mounted integrally with the main computer on the indicator section as shown in figure 25C2. Its appearance is shown in figure 25C24.

25C22. Star-shell computer, functions

The star-shell computer's functions are to compute and transmit the following for control of the guns firing star shells.

1. $B'grjn$—Star-shell gun train order.
2. $E'gjn$—Star-shell gun elevation order.
3. Fn—Star-shell fuze-setting order.

By positioning the proper switches at the fire control switchboard, these outputs are transmitted to the guns firing star shells over the regular circuits used for gun train, gun elevation, and fuze-setting orders from Computer Mark 1A. They are derived from the following inputs:

Mechanical from the Computer

1. $B'gr$—Gun train order.
2. $E'g$—Gun elevation order.
3. $R2$—Advance range.
4. $WrD+KRdBs$—Star-shell deflection rate.

Electrical from the Star-Shell Spot Transmitter in the Director

5. $B'jn$—Star-shell deflection spot.
6. $E'jn$—Star-shell elevation spot.
7. Rjn—Star-shell range spot.

Manual

8. Rjn—Star-shell range spot.
9. $R2n$—Star-shell range.

Star-shell deflection rate ($WrD+KRdBs$) is used to correct $B'gr$ (from Computer Mark 1A) for motion of the star due to wind and relative target motion such that, at half the burning life of the star (about 30 seconds), the point of illuminations is in the vertical plane containing the line of sight and behind the target. Star-shell fuze (Fn) and gun elevation ($E'gjn$) orders will cause the star to form 1,500 feet above and 1,000 yards beyond the target.. Thus $E'gjn$ must include a correction to compensate for the fall of the star between the time the projectile bursts and the star is formed.

Star-shell range spots (Rjn) are used to alter both the elevation and the fuze orders. Star-shell deflection spots ($B'jn$) and star-shell elevation spot ($E'jn$) are used to correct the train and elevation orders respectively. All spots normally are transmitted to the star-shell computer by the star-shell spot transmitter in the director.

25C23. Star-shell computer, operation

The dials and knobs used in the operation of the star-shell computer are shown in figure 25C24. Star-shell range spot (Rjn) is sent to the center dial in the right-hand dial group by synchro transmission from the star-shell spot transmitter in the director. The only marking on the center dial is the white pointer shown in the figure. The ring dial is graduated to read spots applied to the instrument against the fixed index shown in the figure, and is rotated by the range spot knob. To introduce Rjn into the computing mechanism of the instrument, the operator turns the range spot knob to place the index on the ring dial opposite the pointer on the center dial.

Star-shell range ($R2n$), which is the horizontal advance range measured to the point of star-shell burst, is displayed on the counter between the two dial groups to enable the operator to read the correct value of $R2n$ required as the input to the left-hand dial group.

The dial group to the left of the instrument (labeled star-shell range dials) consists of an inner dial and a ring dial, both of which indicate star-shell range ($R2n$) against the fixed index. The inner dial is the fuze dial, and is graduated to compute Fn as a function of $R2n$. By pushing the range knob to its IN position and setting the value of $R2n$ against the fixed index, star-shell fuze order is set into the instrument. The ring dial supplies inputs to the instrument required in the computation of star-shell gun train and elevation orders. To enter the correct input into the instrument, the range knob is pulled to its OUT position and turned to make the ring dial read the correct value of $R2n$ against the fixed index.

In order to operate the star-shell computer, Computer Mark 1A must be set up for control of surface fire against the target to be illuminated by the star-shell fire. The main computer can be used to control

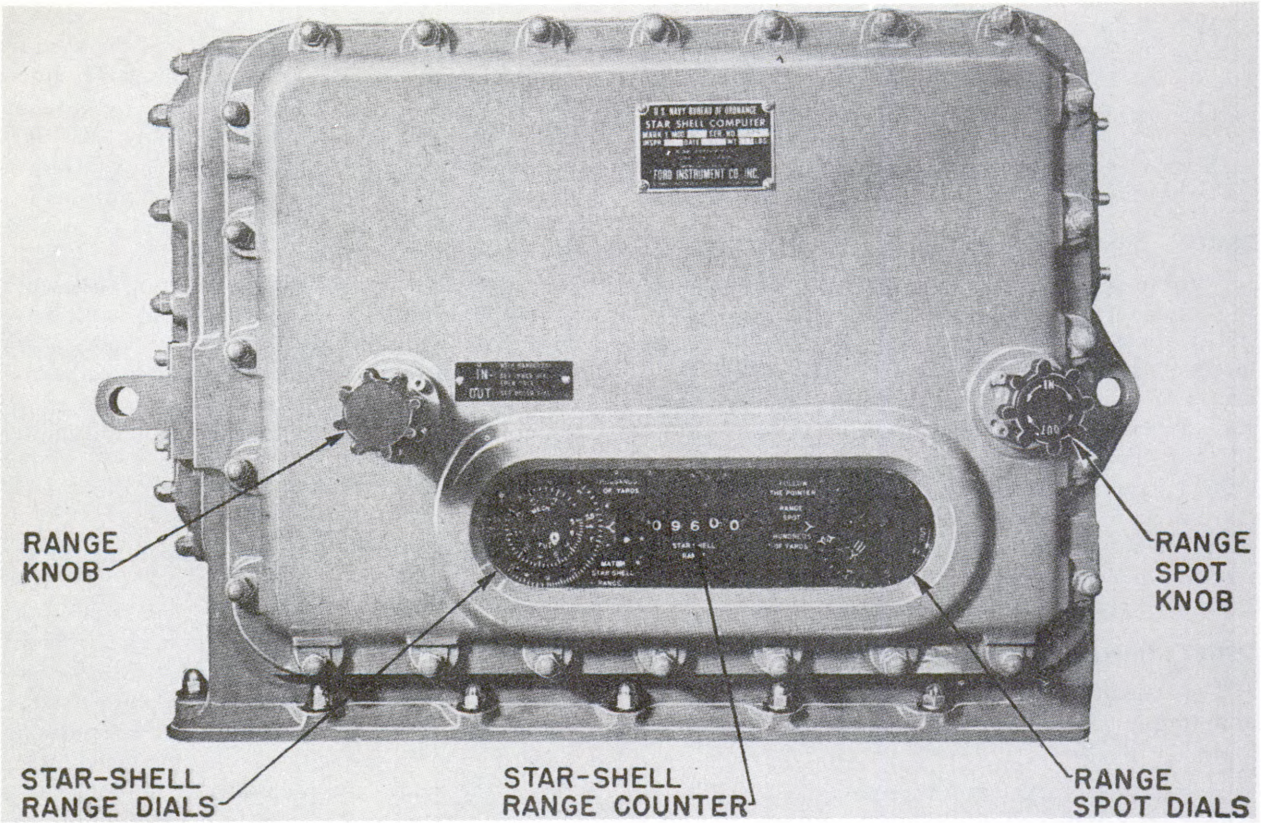


Figure 25C24.—Star-Shell Computer Mark 1.

the guns firing service projectiles against the same target. However, if spots are introduced for the service projectiles, they must be neutralized by opposite spots at the star-shell spot transmitter, since the star-shell gun orders are based upon the Computer Mark 1A gun orders.

25C24. Personnel

The full operating crew for the computer consists of a range operator, a bearing operator, an elevation operator, a synchronize-elevation operator, and a star-shell computer operator. In addition, a stable element operator and a switchboard operator are required for each computer–stable element combination. The synchronize-elevation operator and the star-shell computer operator usually double as the sight setter's talker and fuze setter's talker to the guns, since they can readily read the dials on the computer indicator section. When manual follow-up of the stable element is required, usually one of the latter two operators assists in this operation.

The computer crew on ships with one computer-stable element combination to a plotting room is under the immediate direction of the plotting-room officer, who does not usually function as an operator. In plotting rooms containing two systems, each computer crew usually is supervised by a junior officer in charge of one computer–stable element combination.

D. Mark 6 Stable Element

25D1. Introduction

The Mark 6 stable element (fig. 25D1) is one of the three major units of the Mark 37 gun fire control system. It is located in the plotting room adjacent to the Mark 1A computer, as shown in figure 25C2. In general, the primary function of the Mark 6 stable element is equivalent to that of the stable vertical in the main-battery system; that is, it measures level angle (L) and crosslevel angle (Zd)—angles caused by the variation of the position of the deck of the ship with respect to the horizontal and hence required in the solution of the fire control problem. As will be explained in subsequent articles, the stable element accomplishes this function by using a gyroscope to establish the true vertical and its associated true horizontal plane.

25D2. Gyroscopic principles

As explained in article 19G2, a gyroscope has two properties that make it useful in fire control. These properties are *gyroscopic inertia,* and *precession.* Because of its inertia, a spinning gyro tends to keep its axis pointed in a fixed direction in space. Because of precession, it tends to tilt its axis in a direction at right angles to that of any force applied to it.

25D3. Righting system

Solution of the fire control problem requires that we know the true vertical and horizontal, so that the level angle (L) and crosslevel angle (Zd) can be measured. In the Mark 6 stable element, the righting system makes the gyro axis assume and maintain a true vertical position. This system has two principal parts: the mercury control system and the latitude correction system.

Mercury control system. This system introduces a righting force which causes the gyro spin axis to precess to the vertical and, in addition, counteracts the effects of friction, acceleration forces, shocks, and other disturbances which would tend to displace the spin axis from the vertical.

Essentially the mercury control system consists of two tanks containing mercury, attached to the casing which houses the gyro wheel, on diametrically opposite sides of the wheel. These two tanks are joined by two narrow connecting tubes as shown in figure 19G4. The top tube is merely an air-pressure equalizing connection between the two tanks. The lower tube permits the free flow of mercury from either tank to the other. As long as the gyro wheel is exactly horizontal, the mercury level in both tanks will be the same; but as soon as the wheel is tilted from the horizontal by some external force, gravity will cause mercury to flow from the high tank to the low tank. The additional mercury in the low tank will then produce the same effect as a downward pressure exerted at the low point of the gyro wheel.

Application of the rule of precession shows that this will only cause the wheel to precess more out of the horizontal in a direction 90° away. However, if the mercury effect is applied not at the low point but 90° from the low point, pressure at this point will cause the low point of the gyro to precess upward to its original horizontal position, at which point the mercury is redistributed equally.

This effect is accomplished in the stable element (1) by a *gimbal rotation motor* which rotates the entire gyro assembly and attached mercury tanks at 18 rpm in the same direction as gyro spin, and (2) by installation of an orifice to regulate the flow of mercury in the lower connecting tube. The net result is that, by the time the mercury has reached the low tank, the low tank has been displaced 90° from the low point of the gyro wheel, and the pressure exerted here causes the gyro spin axis to precess back into the vertical. This, moreover, is exactly what takes place when the gyro is first started. As a result of mercury flow and gimbal rotation, the gyro spin axis automatically erects itself and settles in the vertical after several minutes of operation.

At times certain irregularities of ship motion, such as sharp turns or speed changes, occur which cause an irregular flow of mercury, tending (as the result of either centrifugal force or inertia) to displace the gyro spin axis from the vertical rather than to right it. To prevent mercury flow at such times, a *mercury cut-out valve* closes, thus blocking the lower connecting tube. This valve is operated automatically by a cut-out control on the stable element's control panel.

Latitude correction system. It was shown above that the mercury control system brings the spin axis of the gyro to the vertical. However, effective operation of that system depends upon a definite displacement of the spin axis from the vertical. Consequently, if the mercury control system were to act alone, the gyro spin axis still would deviate slightly from the vertical as a result of the apparent tilt caused by the earth's rotation. In other words, the spin axis would be continuously lagging, but attempting to regain, its vertical position.

Figure 19G3, depicts the effect of the earth's rotation on a free gyro. A gyro located at either pole, such as gyro A in the center illustration, will be unaffected by the earth's rotation, inasmuch as a plane tangent to the earth at either of these points remains parallel to its original position in space.

On the other hand, a gyro located at the equator will assume the successive positions with respect to the earth shown in the left-hand illustration. To an observer standing on the earth, the wheel will appear to turn completely over every 12 hours; that is, to turn backward (toward the west) with respect to the earth's rotation at the rate of one revolution every 24 hours.

At any point between the pole and the equator, as shown in the center and right-hand illustrations, the gyro wheel will appear to gyrate once every 24 hours about an axis parallel to the axis of the earth's rotation and in a direction opposite to that of the earth's rotation. This effect can be compensated for if the gyro can be made to precess slowly to the eastward at the same rate as the earth's rotation. The gyro's plane of rotation will then remain parallel to the horizontal plane.

This is accomplished in the stable element by means of a latitude correction system which consists essentially of a latitude weight and a latitude motor. The latitude weight is so arranged as to cause a downward pressure at the north point of the gyro wheel, resulting in an easterly precession. The position of the latitude weight is adjustable, so that the weight can be set for the latitude in which the ship is operating. Usually it is considered sufficient to make a latitude setting once a day.

To ensure that the latitude weight remains properly oriented in a northerly direction so as to cause easterly precession of the gyro, certain factors must be taken into consideration. The latitude weight, as shown in figure 19G5, is mounted at the upper end of the gyro assembly. The gyro assembly, however, does not remain stationary. It turns with the ship (in a horizontal sense) during a change of course (Co); it is rotated by director train ($B'r$), as will be explained in a subsequent article, to permit proper measurement of level angle (L) and crosslevel angle (Zd); and, finally, it revolves at 18 rpm to permit proper operation of the mercury control system as previously pointed out. Obviously then, provision must be made to cancel out the effects of Co, $B'r$, and 18 rpm if the latitude weight is to remain in a northerly direction.

This is done in the stable element by a synchro known as the *latitude motor*. The rotor of this motor supports the latitude weight, and the stator is attached to the gyro case. The electrical input to the motor positions the rotor with respect to the stator. Consequently this input must be the sum of own-ship course (Co), training gear rotation ($B'r$), and gimbal rotation (18 rpm) if the latitude weight is to remain properly oriented.

Two differential generators, which, in effect, are electrical differentials, are employed to make up this electrical input to the latitude motor. As illustrated schematically in figure 25D2, input Co goes to the director train differential (mounted in the base of the instrument) where $B'r$ is added to it. The sum, $Co+B'r$, goes to the gimbal rotation differential (mounted on the level frame). There 18 rpm is continuously added to $Co+B'r$. The output to the latitude motor stator, $Co+B'r+18$ rpm, holds the latitude motor's rotor stationary with the weight in a northerly direction—the 18 rpm effectively stopping the rotor on the LOS, $B'r$ effectively bringing the rotor to the fore-and-aft axis of the ship, and Co orienting the rotor to North.

25D4. Mechanical construction

The Mark 6 stable element, like the stable vertical used in the main-battery fire control system, consists essentially of a sensitive element and a measuring group.

Sensitive element. This is the heart of the instrument and consists of the gyro, gyro case, gyro gimbal, and a fork-shaped support known as the rotating fork. Figures 19G4 and 19G5 illustrate these parts in the stable vertical's sensitive element. Corresponding parts in the stable element are essentially the same.

Figure 19G4 shows the gyro proper. The wheel is carried on an axle supported by ball bearings at the upper and lower ends of the gyro case, the wheel and case forming the rotor and stator respectively of a high-frequency induction motor. A squirrel-cage winding, consisting of solid conducting bars, is in the gyro wheel, while wire stator windings are in the gyro case. A special motor-generator is provided to supply power at a frequency sufficient to drive the gyro at about 8,500 revolutions per minute.

The gyro assembly of figure 19G4 pivots within the gyro gimbal on a case axis perpendicular to the spin axis, as shown in figure 19G5. The gyro gimbal, in turn, is supported by the arm of the rotating fork on the gimbal axis, which is perpendicular to both the case axis and the spin axis. This axis arrangement provides a universal mounting giving the gyro three degrees of freedom, and allows it to spin on a vertical axis, even though the rotating fork may vary its position from time to time.

Measuring group. This consists of a level gimbal, a crosslevel gimbal, training gear, and as will be described more in detail in a subsequent article, an umbrella and its follow-up coils. Figures 19G6 through 19G8 illustrate the stable vertical's measuring group. The measuring group of the stable element is not entirely the same. The important difference lies in the manner in which level angle (L) and crosslevel angle (Zd) are measured. In the stable element, the outer gimbal is the crosslevel gimbal, supported at its trunnion bearings by the training gear structure (main frame). The outer (crosslevel) gimbal, in turn, supports the inner or level gimbal so that the gimbal axes are mutually perpendicular. It can be seen from this gimbal relationship that, in the stable element, L is measured in a vertical plane while Zd is measured in a plane perpendicular to the deck. This is just the reverse of the measurement of level and crosslevel angles in the stable vertical.

At the lower end of the inner (level) gimbal there is a bearing for the rotating fork. The entire sensitive-element assembly of figure 19G5 is mounted within the measuring-gimbal system of figure 19G6, being supported at its lower end by the rotating fork in this fork bearing, so that it is free to rotate within the measuring group. The complete assembly is shown in figure 19G7. A *gimbal rotation motor*, attached to the lower end of the inner (level) gimbal, is geared to the rotating fork and drives it at 18 rpm. The fork turns the entire sensitive element at this speed within the measuring-gimbal system. This rotation is essential to the mercury control system as explained in article 25D3.

25D5. Follow-up system

The actual measurement of level angle (*L*) and crosslevel angle (*Zd*) in the stable element is similar to the measurement of comparable angles in the stable vertical, and is accomplished by a follow-up system. This system centers about an electromagnet, called a follow-up magnet, and two follow-up coils.

The *umbrella* is attached to and moves with the top of the level gimbal. It contains two *follow-up coils.* The level follow-up coil is imbedded in grooves on the upper side of the umbrella, while the crosslevel follow-up coil is similarly carried on the underside. In effect, each coil is wound in the shape of a figure eight, the turns being clockwise in one loop and counterclockwise in the other.

The line joining the lop centers of the level coil is at right angles to the level axis, which means that it lies in the vertical plane through the LOS when the training gear is oriented by *B'r*. The corresponding line of the crosslevel coil is at a right angle to the crosslevel axis, and therefore lies across the vertical plane through the LOS. The center of each figure-eight coil is on the umbrella center.

The *follow-up magnet* is mounted on top of the gyro case, as shown in figure 19G5, so that its axis coincides with the spin axis. The magnet is energized with alternating current which sets up an alternating magnetic field. This field induces voltages in the follow-up coils. The action of the crosslevel follow-up is the same as that of the level follow-up; hence the rest of this discussion is confined to the level system.

When the umbrella center is on the spin axis, the voltages induced in the two loops of the level coil are equal in magnitude. Since the loops are wound in opposite directions, their voltages at any instant, however, have opposite polarity, and their resultant voltage is zero. When a change in level angle occurs (during rolling or pitching of the ship), the umbrella, which tends to follow the ship, moves off the spin axis in the vertical plane through the LOS. The follow-up magnet, however, remains in the vertical because of the action of the gyro. Consequently, the magnet is then closer to one loop of the level follow-up coil than to the other, and induces a higher voltage in the first loop than in the second.

The resultant voltage across the coil is no longer zero, but has both magnitude and direction which provide an indication of the follow-up action required. The amount that a follow-up must drive automatically or that a handcrank must be turned manually to reposition the level gimbal in the horizontal plane—and hence to return the umbrella to its neutral position on the spin axis—is a measure of level angle (*L*).

25D6. Keys, dials, handcranks, switches

The locations of most of the various keys, dials, handcranks and switches of the Mark 6 stable element can be seen in figure 25D1.

Keys. There are three hand-operated keys on the front of the instrument. The right-hand key is a *hand firing key* that may be put into the firing circuit if desired. It is in no way connected with the internal arrangement of the stable element. However, it may be used with selected fire as will be described in a subsequent article. The middle key is the *automatic firing key.* It operates in conjunction with automatic firing contacts in selected level or selected crosslevel fire. The third key is the *salvo-signal key.* It is used to sound buzzers in the mounts as a warning just before the firing circuit is closed.

Dials. There are three sets of dials under the square window at the top of the instrument. The pair of concentric dials at the front and center indicate the fine and coarse values of director train *B'r* against a fixed index. The two remaining sets of dials each consist of a trio of concentric dials. The inner and intermediate dials respectively indicate fine and coarse generated values against a fixed index. The outer ring dial indicates the selected value against the same index when selected values are being used. The right-hand set of dials registers values of level, while the left-hand set indicates crosslevel. Two galvanometers are located on the top of the instrument, one for level and one for crosslevel. These galvanometers are used in conjunction with the handcranks described below during manual follow-up.

Handcranks. There are two hand-input cranks installed on the stable element. They both have two separate and distinct uses. First, either one or the other may be used to put in a selected value, but both cannot be used simultaneously for this purpose. Secondly, the handcranks can be used in manual follow-up, a procedure which was mentioned in article 25D5 and which will be explained in detail in a subsequent article.

Neither handcrank can simultaneously accomplish both uses. If, for example, the level handcrank were constantly being rotated for manual follow-up in level (to keep the level follow-up coils centered over the follow-up magnet), it could not concurrently be used to set in a selected value of level. Both handcranks are either engaged or disengaged by magnetic clutches which are controlled by the selector and follow-up switches described below.

Switches. Three switches are installed on the stable element for its control. They are: the selector switch, the crosslevel follow-up switch, and the level follow-up switch. The first two can be seen on the front of

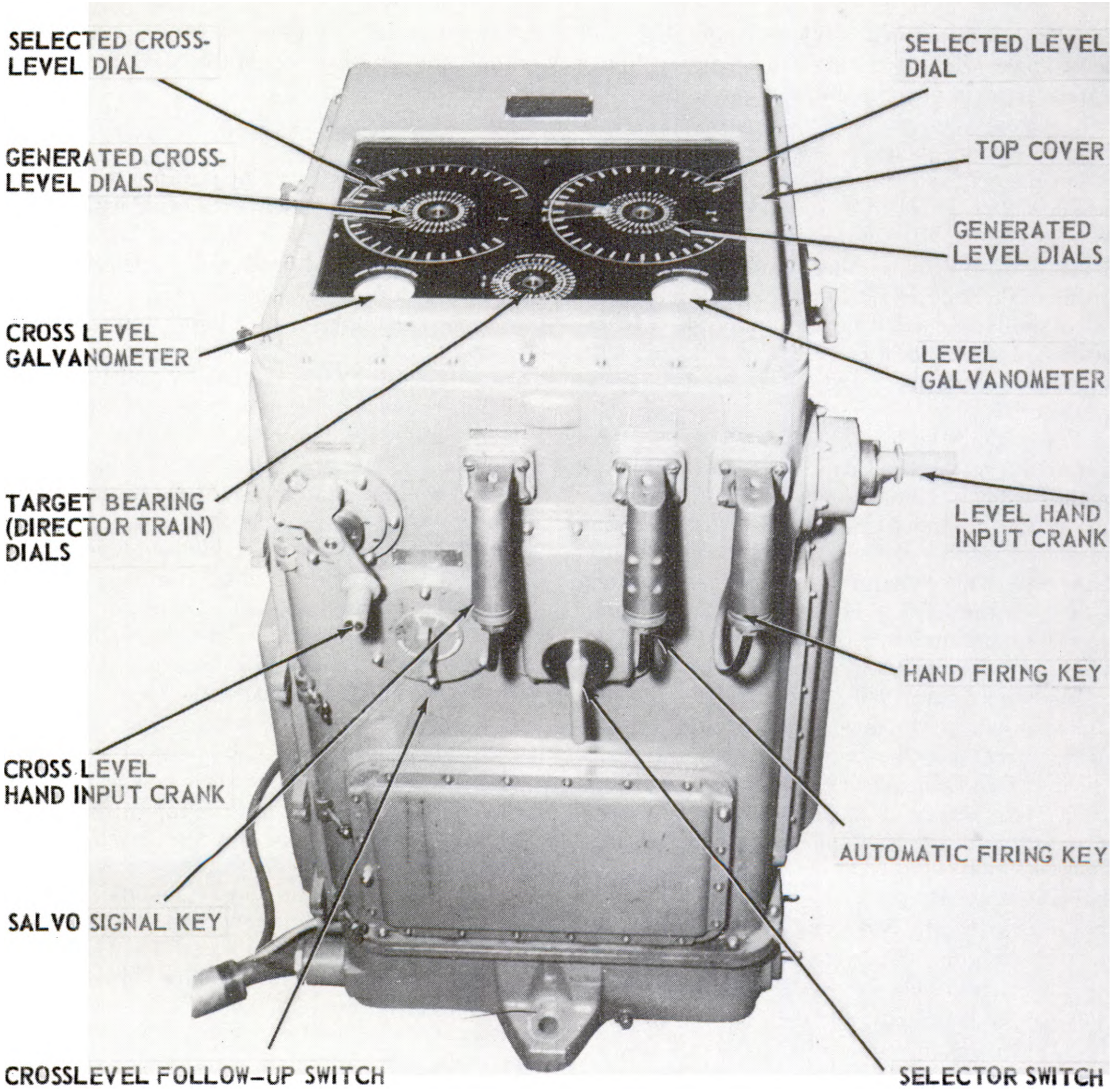


FIGURE 25D1.—Stable element.

the instrument in figure 25D1. The third is located to the right of the level hand-input crank on the right side of the instrument.

The *selector switch* is used in selecting the type of fire desired. It has three positions labeled LEVEL FIRE, CONTINUOUS FIRE, and CROSSLEVEL FIRE. When the selector switch is thrown to a selected type of fire (for instance, level or crosslevel), it causes the corresponding handcrank to become engaged.

The two *follow-up switches,* which are identical in operation, control the method of follow-up used. Each has two labeled positions, AUTOMATIC and MANUAL. The switches have nothing to do with the type of fire used but, if a switch is on MANUAL, its corresponding handcrank, already being used for manual follow-up, cannot be used for selected fire. For example, if the level follow-up switch were on MANUAL, selected-level fire could not be used but crosslevel fire could be used; therefore, in this particular instance, the selector switch would have to be on either CONTINUOUS FIRE or CROSSLEVEL FIRE.

25D7. Inputs and outputs

The inputs and outputs of the Mark 6 stable element are summarized below, together with their more important uses. Most of them have been discussed previously, either in the preceding articles or in the study of the Mark 1A computer and the Mark 37 director.

Inputs

Quantity	*Received from*	*Used*
1. $B'r$	Computer . . .	To assist in making up L and Zd; to orient gimbals to LOS; to orient latitude weight to North.
2. Co	Gyro compass	To orient latitude weight to North.
3. Own ship's latitude.	Set manually.	To counteract for earth's rotation effect on gyro.
4. Lj or Zdj.	Set manually.	In selected fire.

Outputs

Quantity	*Sent to*	*Used*
1. Zd	Director	To stabilize optics and radar antennas.
2. Zd or Zdj.	Computer . . .	To compute Br from $B'r$; to compute trunnion-tilt correction.
3. L or Lj. .	Computer . . .	To compute E from Eb, Br from $B'r$, and trunnion-tilt correction.
4. $L+Zd/30$	Computer . . .	To make up elevation correction.

It should be noted that all outputs to and inputs from the computer, listed above, are transmitted mechanically by shafting. On the other hand, Co and the value of Zd sent to the director are both electrically transmitted.

25D8. Director-train transmission

It was mentioned previously that director train ($B'r$) actually rotates the training gear in the stable element and hence keeps the axis of the crosslevel (outer) gimbal oriented in the vertical plane through the LOS. This is shown in figure 25D2. Within the crosslevel gimbal is carried the level gimbal, its axis being at right angles to the crosslevel gimbal's axis. Thus the input of director train ($B'r$) positions both gimbals so that level angle (L) is measured in the vertical plane through the LOS and crosslevel angle (Zd) in a plane at right angles to both the vertical plane through the LOS and the deck plane. The quantity $B'r$, in addition, has other uses. It drives the director train dials on top of the stable element; it assists in holding the latitude weight in a northerly direction as explained in article 25D3; and finally, it is used in determining crosslevel angle (Zd) and level angle plus crosslevel function ($L+Zd/30$) as will be explained in a subsequent article.

25D9. Gear walking

The crosslevel gimbal is connected to the crosslevel follow-up motor by a gear train and shafting which may be driven either by the motor or by the crosslevel handcrank as can be seen in figure 25D2. The drive passes through the training gear. When the latter turns, a pinion in the gear train "walks" on another gear in a manner similar to the walking of the pinion on the floating gear in director telescopes. This walking is a function of the direction train, $f(B'r)$, similar in nature to the crosslevel function $Zd/30$. The follow-up motor (or handcrank) must therefore supply the quantity $Zd+f(B'r)$ to the shaft driving the crosslevel gimbal, in order to move the gimbal through the angle Zd to its original horizontal position.

The level gearing is similar in many respects to the crosslevel gearing. However, in addition to passing through the training gear it also has to pass through the crosslevel gimbal to reach the level gimbal. Consequently, crosslevel gimbal motion causes walking of a pinion in the level drive. This gear walking causes motion of the level gimbal in an amount equal to a function of crosslevel. This motion must be compensated for by rotation of the level shafting. The gear ratio used makes this function equal to $Zd/30$ to match the function required at the director telescopes. The level follow-up motor (or the level handcrank must therefore supply the quantity $L+Zd/30+f(B'r)$ to the shaft driving the level gimbal in order to move the gimbal through the angle L to its original horizontal position.

25D10. Operation: automatic follow-up

As explained in article 25D5, when the center of the umbrella moves away from its neutral position over the follow-up magnet, a voltage is induced in at least one of the follow-up coils. The only difference between automatic follow-up, described herein, and manual follow-up, presented in the next article, is the manner in which this follow-up coil voltage is employed. For example, when the level follow-up switch is set on AUTOMATIC, it connects the level coil to the level follow-up units on the control and follow-up panel.

At the panel, the coil voltage is amplified and used to control rectifier tubes which supply direct current to the level follow-up motor. The direction of the current flow determines the direction of motor rotation. The current is applied so that the motor drives the level ring in a direction that will place the um-

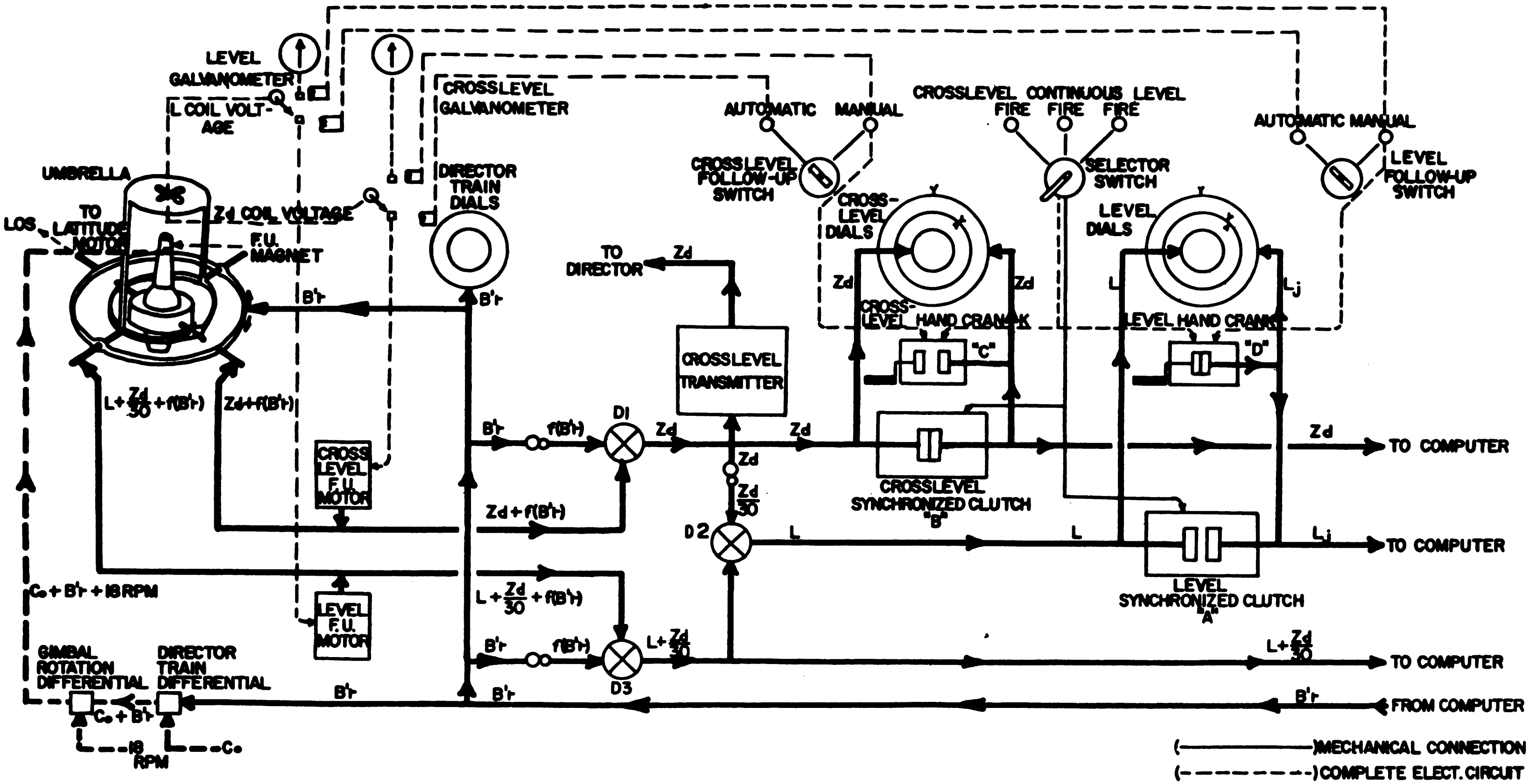


Figure 25D2.—Functional diagram of Stable Element Mark 6 (set up for selected level and automatic follow-up).

brella center back on the spin axis. The amount that the level follow-up motor will drive, of course, as explained in article 25D9 and as shown in figure 25D2, is the quantity $L+Zd/30+f(B'r)$.

The response is made sufficiently sensitive to cause the umbrella center to remain very nearly in line with the magnet. In other words, the follow-up motor functions practically as soon as displacement begins, so that the generation or measurement of L is continuous. If the motor were permitted to drive until the signal voltage became zero, of course, it would coast, as a result of its inertia, and actually drive the level gimbal and the umbrella slightly beyond their neutral positions (in the horizontal plane and on the spin axis, respectively).

Then the follow-up control would operate to run the motor in the reverse direction, and it again would coast beyond the desired position. To prevent this action, which is called "hunting", an anti-hunt unit is included in the controls at the panel. It operates to shut off the power slightly before the neutral position is reached. A sensitivity control permits adjustment of this action to suit the requirements of individual ships.

Automatic follow-up in crosslevel is accomplished in the same way as in level; that is, the crosslevel follow-up switch is placed on AUTOMATIC, and the crosslevel follow-up motor drives an amount equal to $Zd+f(B'r)$ to return the umbrella to its neutral position.

25D11. Operation: manual follow-up

Automatic follow-up normally is used in the operation of the stable element. However, in case of failure, one or both of the automatic follow-up systems can be replaced by manual follow-up. For example, if the level follow-up motor is inoperative, manual follow-up in level can be used to keep the umbrella centered on the spin axis and thus to ensure the proper measurement of level angle (L). To accomplish manual follow-up in level, the level follow-up switch is set on MANUAL. This setting does three things: It connects the level follow-up coil directly to the level galvanometer; it breaks the armature field circuit of the level follow-up motor, thus causing the motor to idle; and it causes the level handcrank clutch, labeled D in figure 25D2, to become engaged.

Any voltage applied to the galvanometer displaces its needle from the zero position, the amount of the displacement being a measure of level and the direction indicating the required direction of handcrank rotation. When the needle is displaced, the level handcrank must be turned until the needle once again is at zero. This rotation of the handcrank, in effect, performs the same function as that of the level follow-up motor during automatic follow-up; that is, by driving back through the level-synchronized clutch A and differentials D-2 and D-3 of figure 25D2, it supplies the quantity $L+Zd/30+f(B'r)$ to the shaft driving the level gimbal and hence returns the umbrella to its neutral or zero-voltage position.

Manual follow-up in crosslevel is accomplished in a similar way. The crosslevel follow-up switch is set on MANUAL; the crosslevel handcrank clutch C is engaged; and the handcrank rotation drives back through the crosslevel-synchronized clutch B and differential D-1 to supply the quantity $Zd+f(B'r)$ to the shaft driving the crosslevel gimbal.

25D12. Operation: continuous-aim fire

The Mark 37 system was designed for continuous-aim fire, and it is so used most of the time, usually with automatic follow-up at the stable element in both level and crosslevel. Manual follow-up can be used, as explained in article 25D10, but ordinarily is considered a standby measure.

In continuous-aim fire, the selector switch is set at the CONTINUOUS FIRE position, and the two follow-up switches at either AUTOMATIC or MANUAL. Values of L, Zd, and $L+Zd/30$ are transmitted to the computer, and Zd to the director. Before seeing how these values are transmitted, however, it is essential that the control of the four clutches shown in figure 25D2 be understood. There are two different types of clutches: two synchronized clutches, labeled A and B, and two handcrank clutches, which are magnetic clutches, labeled C and D.

Selector switch control of clutches. The selector switch controls all four of the clutches shown in figure 25D2—the handcrank clutches electrically and the synchronized clutches mechanically. It is relatively simple to remember when these clutches are either engaged or disengaged if certain stable-element operating conditions are considered as "normal". As pointed out in the first part of this article, continuous-aim fire and automatic follow-up are considered "normal" stable-element operating conditions. Under these conditions, the selector switch causes the handcrank clutches C and D to become disengaged (since neither hand crank is required for selected fire or for manual follow-up) and the synchronized clutches A and B to become engaged (so as to permit the transmission of L and Zd to the computer).

In selected fire (which will be discussed in a subsequent article) using automatic follow-up, the selector switch engages and disengages clutches to permit the type of fire desired. For example, for selected-level fire using automatic follow-up, the selector switch would leave the crosslevel handcrank clutch C and the crosslevel-synchronized clutch B in their "normal" conditions, disengaged and engaged respectively. However, to permit the transmission of a selected value of level angle (Lj) to the computer rather than the value of level angle (L) coming from differential D-2, it would act to engage the level handcrank clutch D (so as to permit the cranking-in of Lj to the level dials and the computer) and to disengage the level-synchronized clutch A (so as to prevent transmission of L to the computer, or Lj to differential D-2). This particular clutch arrangement is shown in figure 25D2. One point is important: the selector switch has nothing to do with the type of *follow-up* used; it is used only to select the type of *fire* desired.

Follow-up switch control of clutches. Both follow-up switches function alike; therefore only the crosslevel one will be considered in this discussion. The crosslevel follow-up switch controls (electrically) only the crosslevel handcrank clutch C, and then only when the switch is in the MANUAL position. When the crosslevel follow-up switch is in the AUTOMATIC position the condition of clutch C (engaged or disengaged) is controlled by the selector switch as outlined above. When the crosslevel follow-up switch is set on the MANUAL position, however, it effectively overrides (when necessary) the selector switch control of clutch C and always acts to engage clutch C (so as to permit the use of the crosslevel handcrank in manual follow-up). One point is important here, too: the follow-up switch, as its name signifies, controls only the type of *follow-up* and not the type of *fire* desired.

Crosslevel-angle transmission. It was pointed out in the beginning of this article that, during continuous-aim fire, Zd is transmitted both to the computer and to the director. Whether this transmission is automatic or not, of course, depends on the type of follow-up being used. Refer to figure 25D2. During continuous-aim fire with automatic follow-up in crosslevel, director train ($B'r$) is changed by a gear ratio to $f(B'r)$ and subtracted from the crosslevel follow-up motor output, $Zd+f(B'r)$, in differential D-1 to obtain Zd.

The differential output of D–1 drives the crosslevel transmitter, which sends Zd continuously to the director. The Zd line also goes to the generated crosslevel (inner and intermediate) dials, and through the crosslevel-synchronized clutch B to both the selected crosslevel (outer ring) dial and the computer. During this transmission, clutch B is engaged and the clutch C (the crosslevel handcrank clutch) is disengaged. The intermediate generated dial and the selected dial move in unison, since both have an input of Zd; and the instantaneous value of Zd is supplied to the computer.

During continuous-aim fire with manual follow-up in crosslevel, clutches B and C are both engaged, and the crosslevel handcrank drives Zd into the crosslevel line. This manual input not only feeds back through clutch B and differential D-1 to form the quantity $Zd+f(B'r)$ as explained in article 25D10, but also, concurrently, drives the value of Zd to the computer.

Level-angle transmission. During continuous-aim fire with automatic follow-up in level, differential D-3 removes $f(B'r)$ from the level follow-up motor output, $L+Zd/30+f(B'r)$, to obtain $L+Zd/30$. This is one of the required outputs of the stable element, and is transmitted directly by shaft to the computer.

The function $Zd/30$ is obtained from Zd by a gear ratio and supplied to differential D-2, which subtracts it from $L+Zd/30$. The output L of differential D-2 goes to the generated level (inner and intermediate) dials and through the level-synchronized clutch A to both the selected level (outer ring) dial and the computer. During this transmission, clutch A is engaged and clutch D is disengaged. The intermediate generated dial and the selected dial move in unison, since both have an input of L; and the instantaneous value of L goes by shaft to the computer.

During continuous-aim fire with manual follow-up in level, clutches A and D are both engaged. The level handcrank drives the value of L into the computer, and, by the same shaft, through differentials D-2 and D-3, where $Zd/30$ and $f(B'r)$ are added respectively to form the quantity $L+Zd/30+f(B'r)$, as explained in article 25D10.

Limit stops. In the shafting to the generated and selected dials of both level and crosslevel systems are limit stops which mechanically prevent the transmission of angles exceedng 22½°. In the stops on the generated side are electrical contacts which stop the follow-up motors shortly before the mechanical stops are reached. When ship roll and pitch produce level and crosslevel angles great enough to cause the stops to operate, the stable element is shut down to prevent damage to the equipment.

25D13. Operation: selected fire

Selected fire is frequently used in shore bombardment and may be chosen for use against surface targets in heavy weather. The rate of fire is too slow for use against air targets. As both types of selected fire are essentially similar, only one, selected-level fire, will be described in detail.

The transmission of L and Zd in the stable element during selected-level fire differs from that during continuous-aim fire in, really, only two respects. For one thing, a fixed (that is, selected) value of level angle (Lj) is supplied to the computer by shaft instead of the corresponding, constantly changing value (L) sent during continuous-aim fire. Secondly, as mentioned in article 25D6, only automatic follow-up can be used in level.

In all other ways, however, the transmission of L and Zd during selected-level fire and continuous-aim fire are comparable. The level follow-up motor still drives the generated-level dials with the instantaneous value of L and the level gimbal shaft with the quantity $L+Zd/30+f(B'r)$; the transmission of Zd is exactly the same as described in article 25D11; and, finally, the outputs of Zd and $L+Zd/30$ to the director and computer, respectively, are uninterrupted.

For selected-level fire, the level follow-up switch is placed on AUTOMATIC and the selector switch is thrown to LEVEL FIRE, thus disengaging clutch A and engaging clutch D as shown in figure 25D2. The level handcrank is then used to set in the desired value of selected level (Lj) on the selected-level (outer ring) dial. This value, at the same time, is driven by the handcrank motion into the computer, where it is used in the same way as the normal value of L during continuous-aim fire, but at a fixed value.

Next, the automatic firing key is closed. When the ship rolls to the point at which the generated value of level (L) on the intermediate dial equals the selected value (Lj) on the outer ring dial, the automatic contacts close the firing circuit. If for any reason the automatic firing key is not used, the hand firing key may be put into the circuit. Then, when the generated value (L) matches the selected value (Lj), the hand key is closed, firing the battery.

In selected-crosslevel fire a corresponding procedure is employed with the selector switch set on CROSSLEVEL FIRE and the crosslevel follow-up switch on AUTOMATIC. Then, clutch B is disengaged and clutch C is engaged. Zd and $L+Zd/30$ are still sent to the director and computer respectively. Zdj is entered with the crosslevel handcrank, and firing occurs when Zd equal Zdj.

25D14. Selector drive

During readiness periods, such as condition watches in wartime, it is necessary to keep the stable element running, because of the length of time required for the gyro to erect itself and settle down to smooth operation. But if, during such periods, L and Zd are continuously fed into the computer, there is unnecessary wear on the delicate gear trains of that instrument. The L shaft may be kept from constant movement by setting the stable element to selected-level fire; however, in this setting the Zd shaft will still be in motion as the ship rolls and pitches. To eliminate this motion of the Zd shaft, the selector drive is installed.

Its location and appearance are shown in figure 25C1. The instrument is inserted in the crosslevel shaft between the table element and the computer. It contains a clutching arrangement which is controlled by a shift lever. The three positions of this lever permit the input and output shafts to be disconnected, re-connected and re-synchronized, and locked together again to form a direct drive. Dials and a handcrank, located on the top of the selector drive, are used in conjunction with the shift lever.

To set a fixed value of crosslevel (usually 2,000 minutes) into the computer, the input and output shafts are first disconnected by the shift lever; then the selector-drive handcrank is turned, driving the output shaft until the desired fixed value Zdj is read on the crosslevel dial at the rear of the computer. To return the Zd line between stable element and computer to normal operation, the input and output shafts are re-connected by the shift lever, the selector-drive handcrank is turned until the indexes of both selector-drive dials are matched at the fixed index, and, finally, the two shafts are locked together by the shift lever.

Chapter 26

RELATIVE-RATE ANTIAIRCRAFT SYSTEMS

A. Fire Control Problem

26A1. Introduction

Increased aircraft speeds in World War II made necessary the development of fire control systems which could further reduce the time required for solution of the antiaircraft fire control problem. This step was vitally necessary for the control of machine guns, for which the solution time is limited by the relatively short effective range of the weapons. Inasmuch as an individual system is provided to control each mount, the fire control system had to be limited in size and weight. Furthermore, since the greatest danger to the ship was from incoming targets at close ranges, many of the factors computed by such a fire control system as the Mark 37 could safely be ignored. The result was the development of a family of lead-computing or relative-rate systems which differ from the Mark 37 fire control system in that they measure the rates of change of bearing and the elevation directly as angular quantities, and measure these quantities simply by tracking the target. Although originally used for machine guns, systems of this type have now been developed to control guns as large as 6-inch at close and intermediate ranges.

Some relative-rate systems offset the line of sight from the fore-and-aft axis of the sight case by the amount of computed lead angle, so that the sight case itself is aligned with the gun bore axis. These systems are known as *disturbed-line-of-sight* systems. Most lead-computing sights are of this type. Other systems, however, measure the lead angles and transmit them to a computer which makes up the gun orders, while leaving the sight telescope, fixed in relation to the sight case, in the line of sight. These are known as *undisturbed-line-of-sight* systems.

Gun Sight Mark 15 and Gun Fire Control System Mark 63, which are examples of disturbed-line-of-sight systems, are described in some detail in this chapter.

26A2. Lead angles

The hunter who shoots ducks on the wing knows that he must lead the duck by a sufficient angle to compensate for the duck's travel while the load of shot is in the air. A moment's reflection will show that if the duck is climbing, the hunter must lead in elevation; if it is flying across the hunter's line of sight, there must be a lead angle across the line of sight, in traverse. The actual lead angle is the resultant of these two components.

Lead angles in AA fire are analogous. Tracking the usual air target calls for lead in both traverse and elevation to compensate for target motion during time of flight. This may be illustrated by pointing a finger at a flying airplane and following it for a time. The rate at which the finger moves in following the flight of the plane is a rough measure of the angular velocity of the line of sight. The angular velocity of the line of sight, when measured accurately and adjusted for time of flight and for ballistic corrections, becomes the total lead angle. More precisely, the total lead angle may be defined as the angle between the line of sight to the present target position and the position of the gun bore axis required to hit the target at the end of the time of flight. This is illustrated in figure 26A1.

Total lead angle may also be defined as target motion lead angle plus ballistic corrections. Target motion lead angle is the angle between the line of sight to the target's present position and the line from gun to target at the end of the time of flight. Target motion lead angle is ordinarily made up of an elevation lead angle, measured in a plane perpendicular to the deck, and a traverse lead angle, measured in the traverse plane. The traverse plane is the slant plane containing the gun or sight trunnion axis and the present position of the target. Although the usage is not strictly accurate, the term *train,* instead of traverse, is usually used for the sake of convenience.

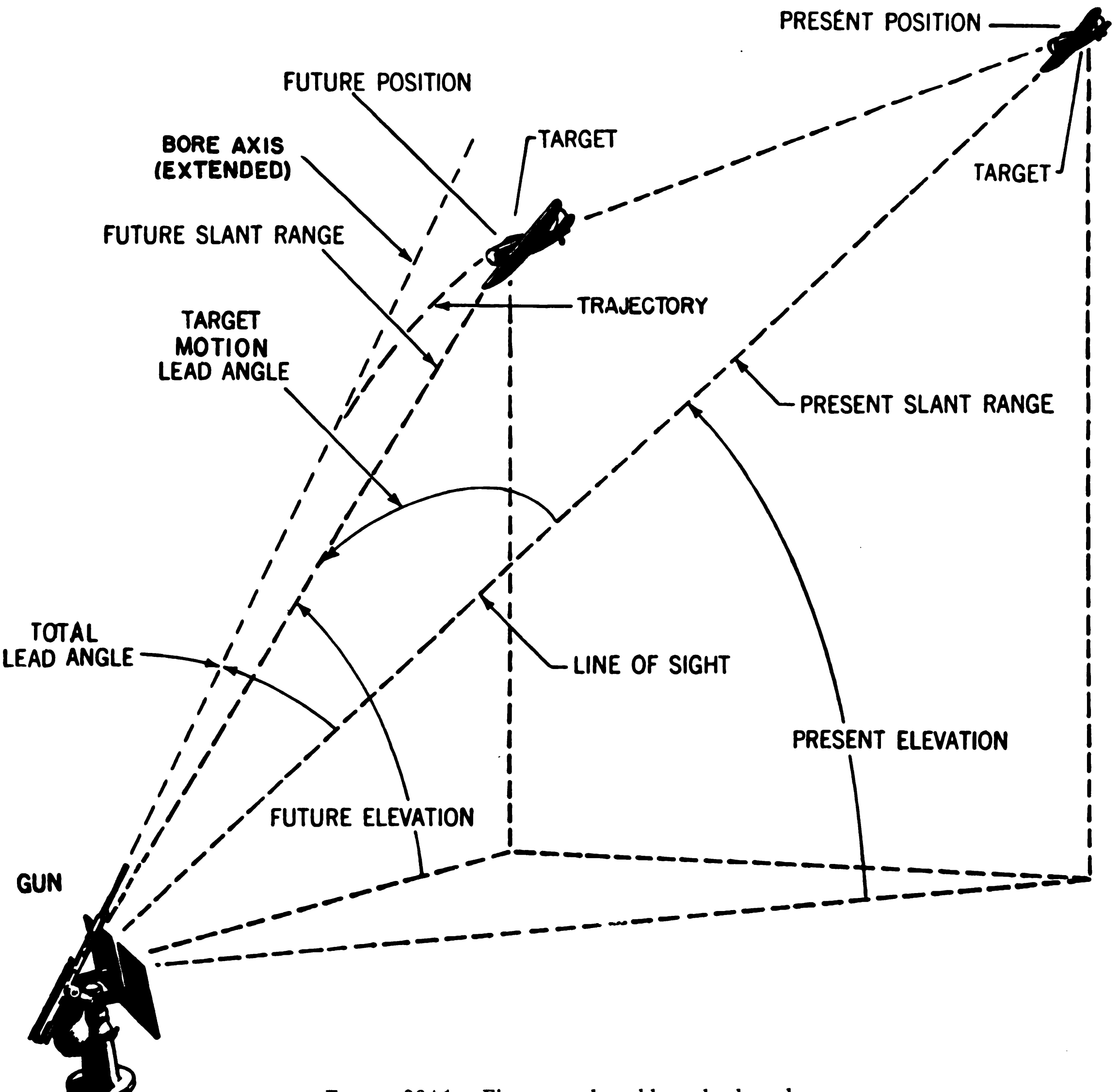


FIGURE 26A1.—Fire control problem; lead angle.

26A3. Superelevation

As shown in figure 26A1, the gun bore cannot be pointed directly at the future target position, because the projectile follows a curved trajectory. A part of this curvature is caused by the downward pull of gravity on the projectile. The correction for this effect is called superelevation. As gravity always acts in a vertical plane, superelevation must be computed in this plane. Superelevation varies with future target range, initial projectile velocity, and future target elevation. Since the force of gravity acts continually on the projectile, the longer the time the projectile is in flight, the greater will be the vertical deviation of the projectile from the gun bore axis. From this it follows that superelevation must vary directly with range, since the time of flight is greater for a greater range. It is also apparent that as initial velocity decreases, superelevation must increase, since a longer time is required for the projectile to reach a given range.

The effect of gravity on the projectile is to pull it down vertically. We are concerned only with the deviation of the projectile from the line of the gun bore axis, however, and so need consider only that component of gravity which is perpendicular to the gun bore axis. It is readily apparent that this component decreases as target elevation increases, and that for a given range, superelevation varies directly as the cosine of the elevation angle of the gun above the horizontal. The effects of range and elevation on superelevation were illustrated by figure 24B6.

26A4. Drift

A second element of the trajectory's curvature is drift, which is a projectile's tendency to move to the right of the extended gun bore axis. Gun barrel rifling causes the projectile to rotate at high speed, thus imparting gyroscopic properties to it. These properties give the projectile a tendency to maintain its axis parallel to the gun bore axis throughout its flight. Since gravity pulls the projectile downward from the line of the gun bore axis, its nose tends to remain elevated above a line tangent to its trajectory. Air resistance against the lower part of the nose of the projectile produces an upward force on the nose. The combination of projectile inertia and air resistance produces a torque which causes the projectile to precess to the right. The effects of drift vary directly with the angle made by the projectile's centerline with the trajectory and with the projectile's time of flight. Since a trajectory departs farther from the line of the gun bore axis at low gun elevations than at high elevations (due to superelevation), drift varies inversely with gun elevation or directly with the cosine of gun elevation. Also, since a longer range requires a longer time of flight and greater superelevation, the effects of drift vary directly with range. This means that for very short ranges drift is small, and it may safely be ignored in lead-computing sights which are designed for firing only at these short ranges.

26A5. Other ballistic corrections

The numerous other factors which affect the trajectory, such as wind, air density variations, and the like, are present in the short-range antiaircraft fire control problem, but in many cases they may safely be ignored, just as drift is ignored in the simpler sights. In unusual cases, where these uncorrected factors cause large errors, they may be corrected by spotting with the assistance of tracers. More complex relative-rate sights and systems, designed for firing at longer ranges, do make corrections for some of these factors.

B. Basic Elements of Lead-Computing Sights

26B1. Introduction

In solving the fire control problem for short-range antiaircraft fire, the various lead-computing sights and relative-rate systems make use of a number of elements which are not used in linear-rate systems such as the Mark 37. Three of these elements will be described in this section: the rate-of-turn gyro, the torque motor, and the pick-off transformer.

26B2. Rate-of-turn gyro

It will be recalled from the study of Stable Element Mark 6 that the two basic properties of a free gyroscope are rigidity of its plane of rotation in space and gyroscopic precession. The functioning of lead-computing sights is based on the principle that the precessional torque exerted by the gyro is directly proportional to the force causing the precession. In order to measure angular rates of target motion, lead-computing sights employ restrained gyros of a type known as rate-of-turn gyros.

A rate-of-turn gyro has only one gimbal, and therefore only two degrees of freedom. Figure 26B1 shows the essential parts of such a gyro. The wheel is free to turn about the axis of spin, and may precess in its gimbal frame about an axis 90° removed from the axis of spin. When a torque is applied by rotation of the gimbal frame about the input axis as shown by figure 26B2, the gyro will precess, or tilt, and will continue to do so as long as the motion continues. Actually, this gyro is mechanically restrained by springs of known stiffness.

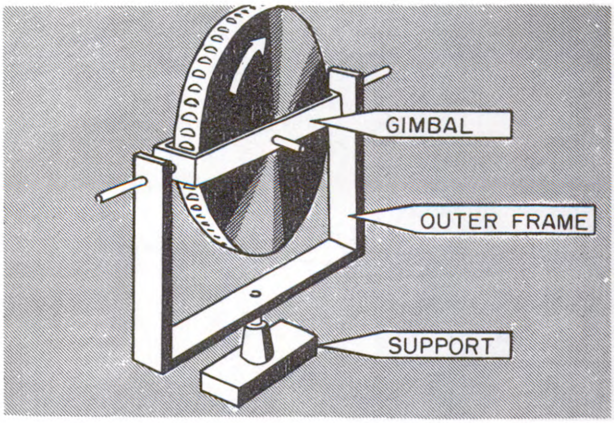


FIGURE 26B1.—Rate-of-turn gyro and mountings.

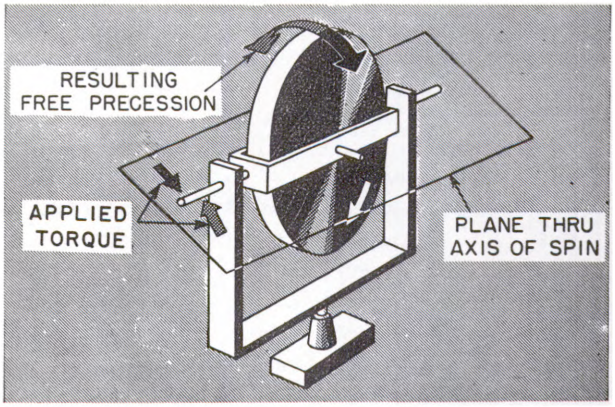


FIGURE 26B2.—Precession of rate-of-turn gyro.

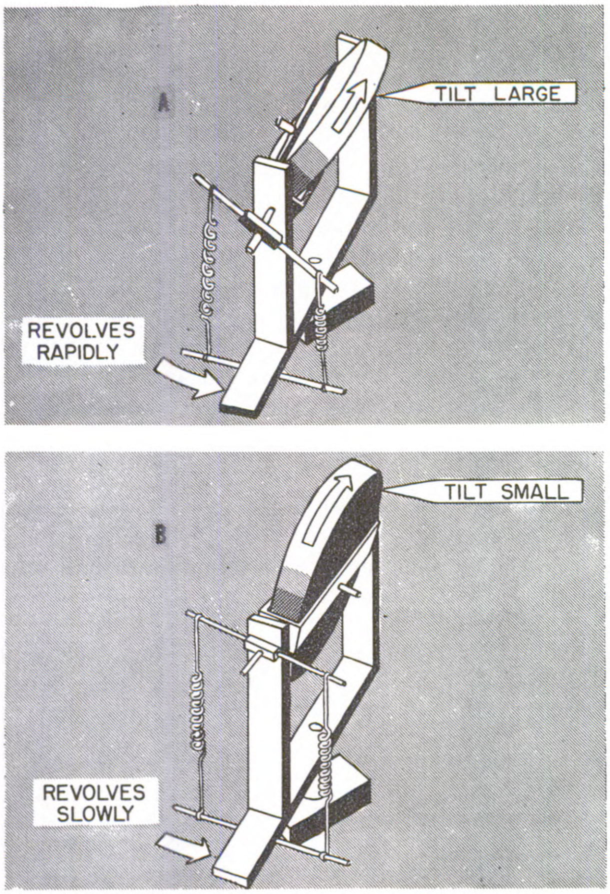


Figure 26B3.—Tilt angle is proportional to rate.

One method by which this might be accomplished is illustrated in figure 26B3. Although the method shown is somewhat simpler than those employed in actual sights, it serves to demonstrate the principle. As soon as the wheel starts to tilt, one spring is extended and the other compressed. The rotor will continue to tilt until the restraining torque exerted by the springs is equal to the precessional torque of the gyro about the output axis. This precessional torque is directly proportional to the rate of turn of the gimbal frame about the input axis. If the gimbal frame is turned rapidly, as in figure 26B3 (A), the gyro rotor will tilt sharply before the two torques are balanced, as in figure 26B3 (A, B). When the gimbal frame is turned more slowly, the rotor tilts to a lesser angle. Since the restraining springs resist the precession of the gyro, the amount of rotor tilt is inversely proportional to the stiffness of the springs. The tilt about the output axis, then, depends upon this relationship:

$$\text{Output angle} = K \times \frac{\text{Applied rate of turn}}{\text{Restraining spring stiffness}}$$

where K is a constant depending on the stability of the particular gyro.

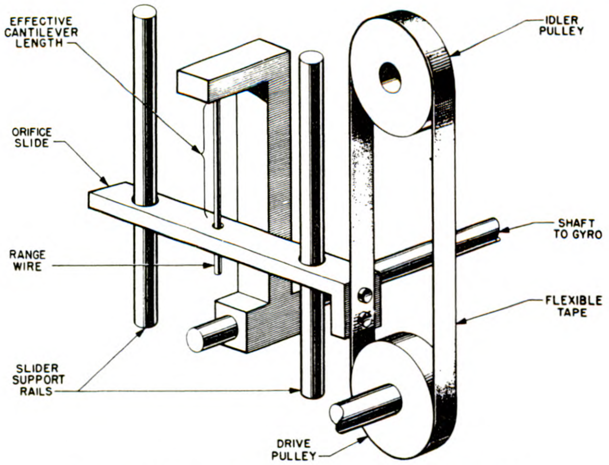


Figure 26B4.—Range wire and slide assembly.

Gun Sight Mark 15, which will be described in this chapter, uses two rate-of-turn gyros having a cantilever type restraining spring, as shown in figure 26B4. The rate-of-turn gyros are used to generate target motion lead angles. The required target motion lead angle is the product of the angular velocity of the line of sight, and the time of flight. The gyros are so mounted within the sight case that when the operator is tracking smoothly, the gimbal frame of one gyro turns about its input axis at a rate equal to the angular velocity of the line of sight in elevation, and the gimbal frame of the other gyro turns about its input axis at a rate equal to the angular velocity of the line of sight in traverse. The two gyros are called the elevation gyro and the train gyro, respectively. The stiffness of the restraining springs is adjustable by moving the orifice slide, as may be seen in figure 26B4. The stiffness of these is adjusted in accordance with the time of flight. Since the lead angle must be greater for a longer time of flight, the restraining spring stiffness is made less for a longer time of flight. Consequently, the rotation of the output shaft is directly proportional to the required lead angle.

It should be stated at this point that Gun Sight Mark 15 is designed for use against high-speed, short-range targets, and is an accurate and dependable system only when so used. It is not suitable for use against targets at long range, for the reason that in such cases the angular bearing rate is so small that tracking cannot set up a dependable solution.

26B3. Torque motor

A torque motor is a motor with a rotor shaft that exerts deflecting torques, and is illustrated schematically in figure 26B5. The magnitude and direction of the output torque depend upon the magnitudes and phase relationship of two a–c input potentials impressed upon the motor stator coils.

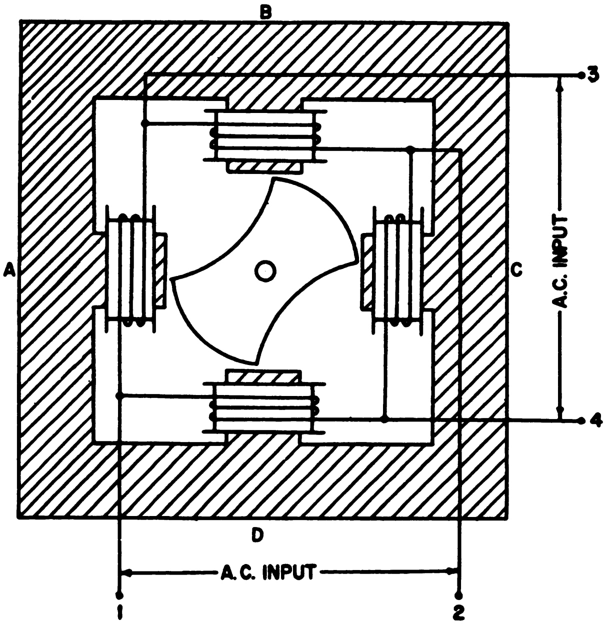


FIGURE 26B5.—Torque motor schematic.

A torque motor consists of a soft iron rotor mounted within a laminated soft iron stator frame, and four coils mounted 90° apart on the stator. The stator coils are connected to form a closed bridge circuit.

Operation of a torque motor may be understood by the analysis of the currents flowing through the various stator coils and the magnetic fields produced by these currents. If the phase relationship of the two input potentials is such that at a particular instant terminals *1* and *3* are negative and terminals *2* and *4* are positive, the currents in coils *B* and *D* will reinforce each other. At the same time, the currents in coils *A* and *C* will be opposing each other. Consequently, the magnetic field between poles *B* and *D* will be stronger than that between poles *A* and *C*. Since the rotor tends to align itself with the magnetic lines of force of the stronger field, it will exert a counterclockwise torque. It should be noted that the rotor is restrained to only a few degrees of rotation, so that it does not completely align itself with poles *B* and *D,* but merely exerts a torque in that direction.

Suppose now that the phase of one of the input potentials is reversed, so that at a particular instant terminals *1* and *4* will be negative and terminals *2* and *3* will be positive. In this case the currents in coils *B* and *D* will oppose each other, while the currents in coils *A* and *C* will reinforce each other. The rotor will now tend to align itself with poles *A* and *C,* producing a clockwise torque.

As a third example, let us assume that no voltage is impressed between terminals *3* and *4*. Now the currents in all coils will be equal, the magnetic fields will be equal, and no output torque will result.

The output torque in each instance is directly proportional to the product of the magnitudes of the two input potentials, and the direction of the output torque is dependent upon the phase relationship of the two inputs.

In some lead-computing sights, torque motors are employed to modify the lead angles to correct for the effect of wind during the time of flight. This is accomplished by mounting the torque motor so that its rotor is attached to the output shaft of the rate-of-turn gyro. The output torque of the torque motor then either aids or opposes the precessional torque of the gyro, thus modifying the generated lead angles. In this case the input potentials represent wind rates.

26B4. Pick-off transformer

A pick-off transformer is a wire-wound inductive electrical element which is used to convert the mechanical angular displacement of a gyro output shaft into an electrical signal for transmission to other components of a relative-rate system. The electrical output signal defines the magnitude and direction of the gyro shaft output. A pick-off transformer is shown schematically in figure 26B6.

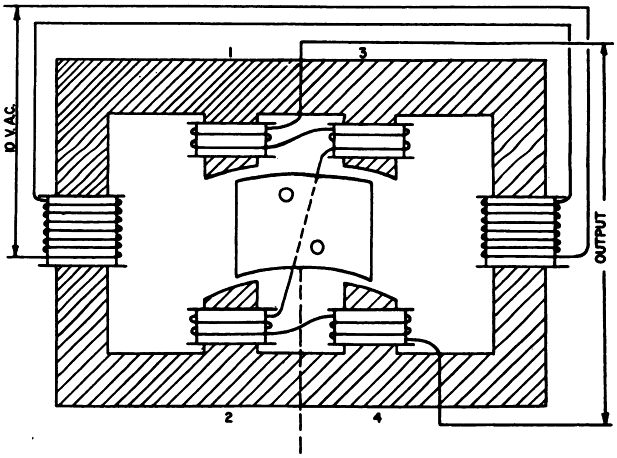


FIGURE 26B6.—Pick-off transformer schematic.

The train and elevation pick-off transformers used in Gun Sight Mark 15 are identical. Each consists of a frame, an inductor, and six coils. Both the frame and the inductor are of laminated, high-permeability steel. Four pole pieces are mounted with the rectangular frame. Two primary coils are wound on the sides of the frame, and four secondary coils are wound on the four pole pieces. The inductor, mounted on an arm attached to the gyro output shaft, moves in the space between the secondary coils.

The pick-off transformer primary windings are connected in series across a 10-volt a–c supply; the secondary coils are connected in series with the output leads. The coils are wound so that the voltages induced in coils *1* and *2* are opposite in phase to those inducted in coils *3* and *4*. When the inductor is centered, the voltage induced in coils *1* and *2* is equal in magnitude and opposite in phase to that induced in coils *3* and *4*. The result is zero output voltage.

When the inductor is moved to the left by rotation of the gyro output shaft, the reluctance (magnetic resistance) of the magnetic path between poles *1* and *2* is less than that of the path between poles *3* and *4*. Because a lower reluctance allows a greater magnetic flux, the voltage induced in coils *1* and *2* is greater than that induced in coils *3* and *4*. This voltage difference becomes greater as the inductor is moved farther from its center position. The output voltage is now equal to the difference between the voltage induced in coils *1* and *2* and the voltage induced in coils *3* and *4,* and has the same phase as the voltage in coils *1* and *2*.

By similar reasoning, when the inductor is displaced to the right of center, another output voltage will be produced. The magnitude of this voltage will depend on the distance the inductor is displaced from center, and its phase will be the same as that of the voltage in coils *3* and *4*. Thus the magnitude and phase of the output voltage indicate the magnitude and direction, respectively, of the gyro output.

C. Gun Sight Mark 15

26C1. Introduction

Gun Sight Mark 15 is an example of a gyroscopic lead-computing sight which is designed for the control of heavy machine guns and dual-purpose guns at short and intermediate ranges. It may be used against targets with range rates up to 350 knots (800 knots in some modifications) and at ranges up to a maximum of 7,500 yards. In addition to its use as a complete fire control system in itself, Gun Sight Mark 15 is used in some modifications of the Gun Fire Control System Mark 63, which will be described later in this chapter.

26C2. Physical description

Figure 26C2 shows a mechanical schematic representation of the Mark 15 sight. The entire mechanism shown in this figure is enclosed in a case, which is shown in figure 26C1. In addition to the mechanism contained in the sight case, several other items of equipment are required. These items include:

1. A supporting platform which provides the freedom of movement in train and elevation necessary for tracking targets.
2. A unit to supply compressed air to drive the gyros.
3. A unit to solve the geometry of wind ballistic corrections.
4. A mechanical means of introducing range and range rate values.

The Mark 15 sight may be mounted on any of several types of supporting platforms. For use as a simple fire control system it is mounted on a Gun Director Mark 51. Such a director is shown in figure 26C3, equipped with a short-range lead-computing sight, the Mark 14, which is somewhat simpler than the Mark 15. For use as a part of a more elaborate system, the sight may be installed on a Mark 52 director, as shown in figure 26C1, or on a Mark 1 director pedestal, as shown schematically in figure 26D1.

An air supply unit is furnished with each sight and installed near the sight. This unit provides a supply of dried, compressed air at a constant pressure to the sight for spinning the rate-of-turn gyros.

Wind rates are transmitted to the sight as a–c electrical potentials by Wind Transmitter Mark 4. This unit receives inputs of own ship's course and speed and true wind direction and speed, and resolves them into traverse wind rate and horizontal range wind rate. These wind rates are sent as electrical inputs to torque motors secured to the output shafts of the train and elevation gyros.

The method of introducing range and range rate into the gun sight varies in different installations. In the simplest arrangement only a knob is provided for each of these inputs. In most cases, however, some type of range receiver is provided. Some of these receivers provide only for matching dials or zero readers manually to introduce range and range rate. Others provide for automatic range input and manual range rate input, while even more elaborate range receivers provide automatic inputs of both range and range rate as received from an associated radar.

26C3. Functional description

Gun Sight Mark 15 utilizes two rate-of-turn gyros, one for train (traverse) lead angle and one for elevation lead angle. The gyros are air-driven, and rotate at approximately 8,300 revolutions per minute. Air to drive the gyros comes from an air supply unit associated with the sight, and in order to maintain a constant speed of rotation of the gyro, the air is kept at a constant temperature and pressure. Each gyro rotor is mounted in a gimbal frame which is in turn mounted in the gyro case by a frictionless suspension. The

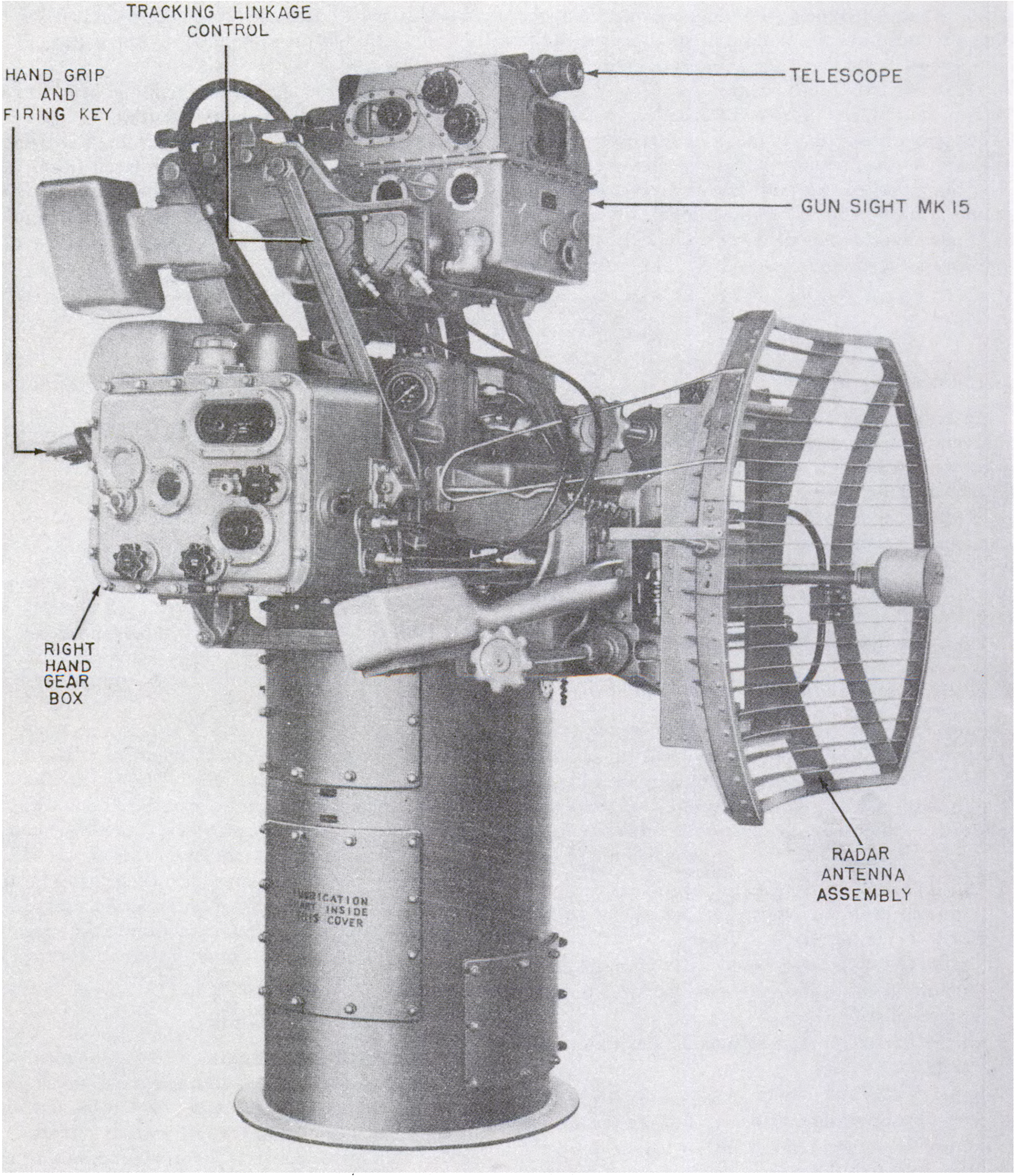


Figure 26C1.—Mark 15 sight installed on Mark 52 director.

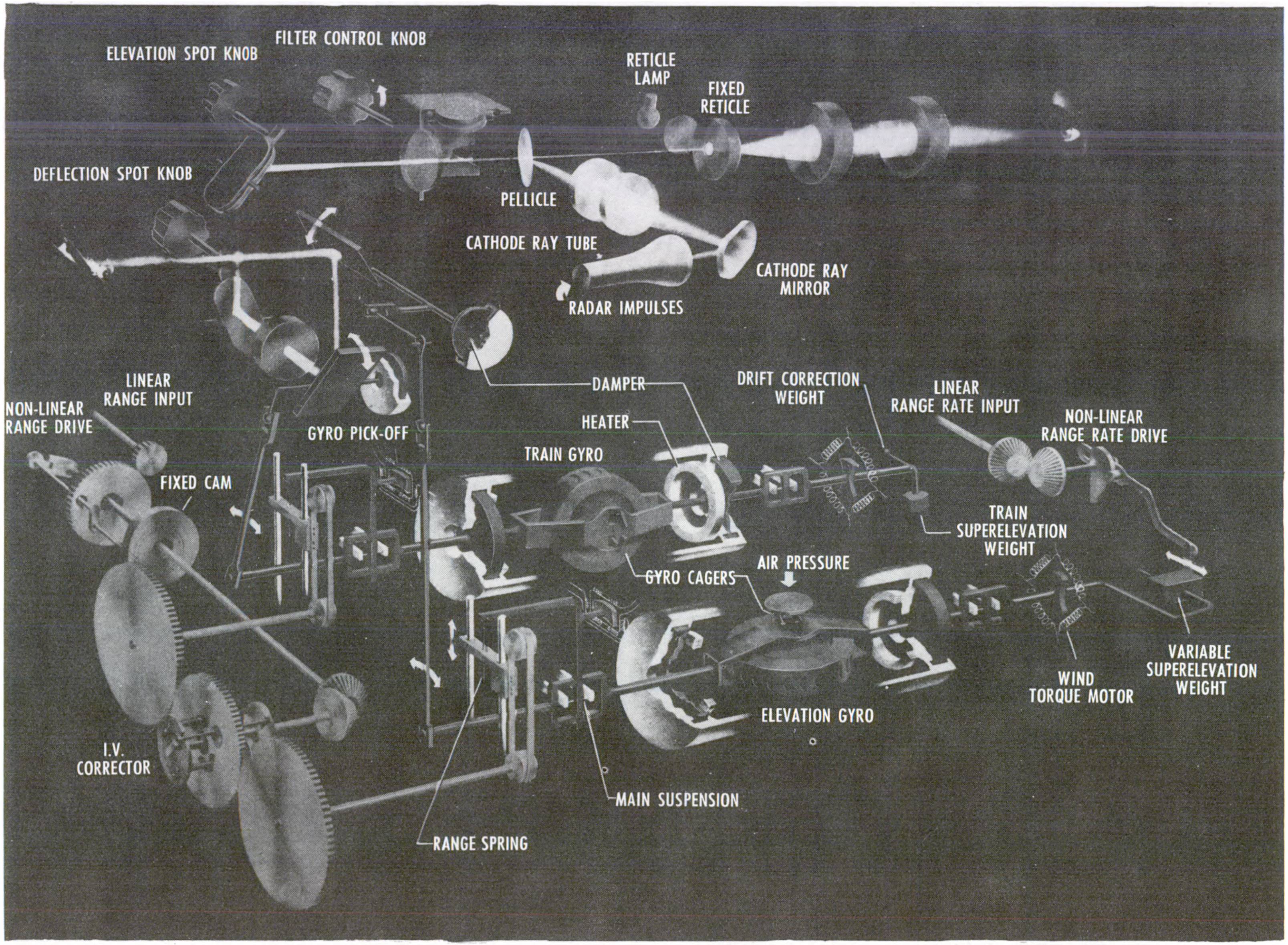


FIGURE 26C2.—Gun Sight Mark 15, mechanical schematic.

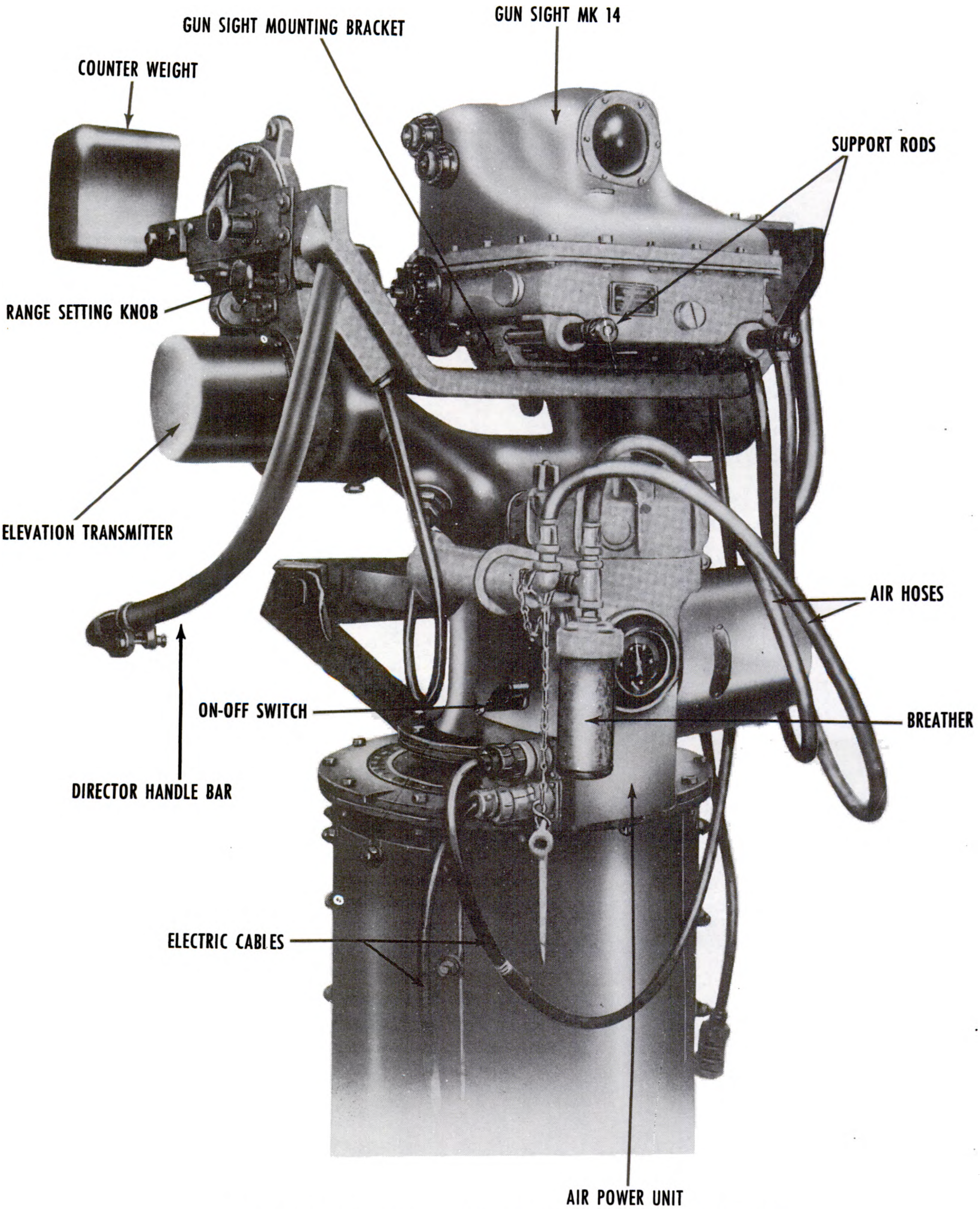


FIGURE 26C3.—Gun Director Mark 51 Mod 2 with Gun Sight Mark 14.

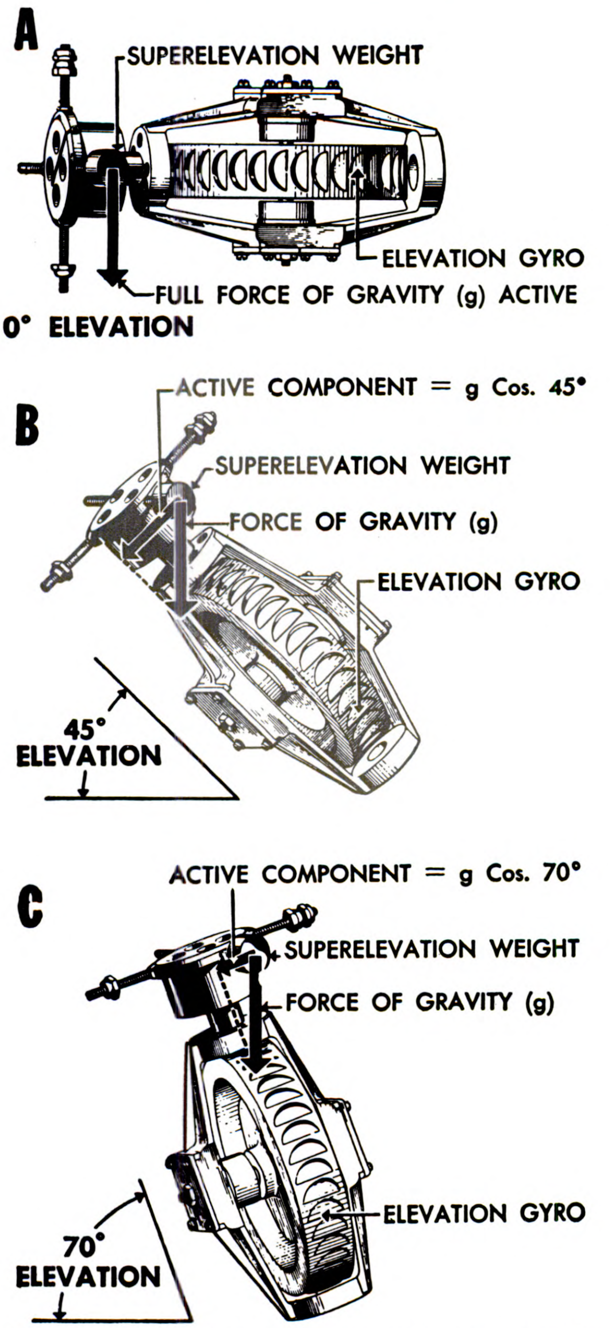


Figure 26C4.—Variation of superelevation with elevation.

gyro rotors are oriented with their spin axes perpendicular to the fore-and-aft axis of the sight case and to each other, so that the train gyro responds only to motion in the traverse plane and the elevation gyro responds only to motion in the elevation plane. Each gyro's output shaft is restrained by a range spring at one end, while on the other end a torque motor is mounted to provide for the introduction of wind ballistic corrections. On the same end as the torque motor are one or more weights for the purpose of making ballistic corrections for drift and superelevation.

Figure 26C4 illustrates the action of the superelevation weight on the elevation gyro. The force of gravity acting on the weight causes a rotation of the gyro output shaft against the restraint of the range spring. Since the range spring is weaker at long ranges, the correction applied at these ranges is greater. Since present range is the range input to the sight, and superelevation should be calculated on the basis of advance range, a variable superelevation weight is provided which can be adjusted to give a larger or smaller correction, depending upon the range rate input. This may be seen in figure 26C2. The effect of the gun elevation on the superelevation weight may be seen from figure 26C4. It will be noted that a superelevation weight is mounted on the train gyro also. The reason for this weight is that superelevation must be corrected in the vertical plane, and if trunnion tilt is present, a vertical correction requires two components; one in train and one in elevation. Thus the effect of trunnion tilt is eliminated. A drift weight is also provided on the output shaft of the train gyro. Its action is similar to that of the superelevation weight on the elevation gyro, with the exception that no correction is made for range rate.

At each end of the gyro case is a damper assembly, consisting of a disc attached to the output shaft of the gyro, and a housing secured to the case. The damper housing is partially filled with a damping fluid in which the disc rotates. The purpose of the damper assembly is to smooth out the response of the gyro during tracking. This makes tracking easier and helps prevent the generation of false lead angles as a result of tracking errors. The damping fluid applies a restraining torque to the output shaft which varies with the rate of change of the lead angle. In steady tracking the lead angle is not changing, in which case the fluid has no restraining effect. Therefore the magnitude of the lead angle is not affected. The damping fluid is very viscous when cold, and its viscosity varies greatly with changes in temperature. In order to prevent changes in the ambient temperature from changing the viscosity of the fluid, and therefore the damping characteristics, internal heaters are used to stabilize the temperature at a value higher than any ambient temperature likely to be encountered.

The optical system of Gun Sight Mark 15 includes a telescope, lead angle mirrors, spot mirrors, an optical filter, a reticle plate, and reticle illumination. In addition, some modifications include a cathode-ray tube and a pellicle for introducing its image into the line of sight. The arrangement of the optical system is shown in figure 26C5. The target image, after entering the

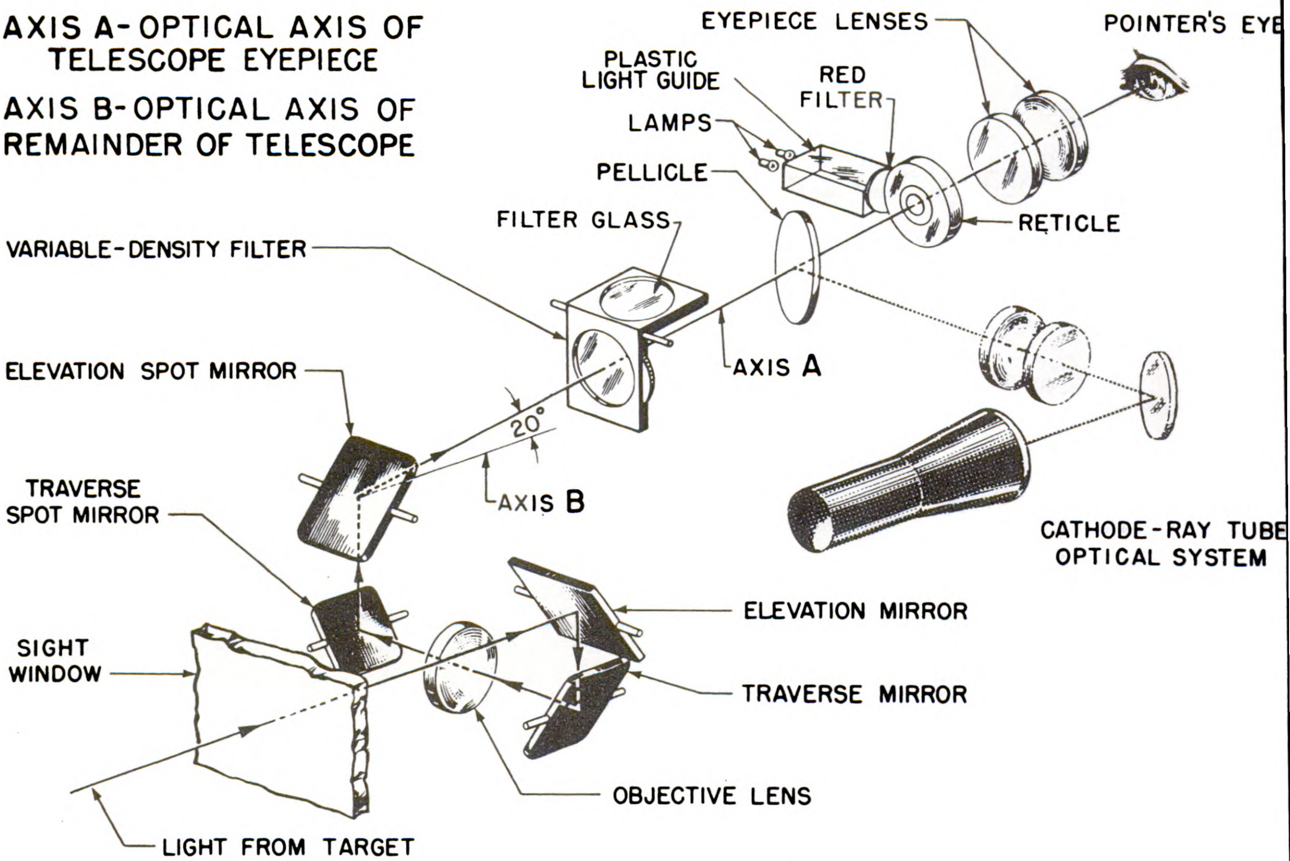


FIGURE 26C5.—Gun Sight Mark 15 optical system.

sight case, is reflected from the elevation lead angle mirror to the traverse lead angle mirror, thence through the telescope objective lens to the deflection spot mirror. From here it is reflected to the elevation spot mirror, and then through the reticle plate to the telescope eyepiece assembly. When either of the gyros precess, it actuate a linkage to offset the corresponding lead angle mirror, thus deflecting the target image. Since the position of the reticle is fixed, this means that the target image will no longer be centered in the reticle. The sight case must then be moved so as to bring the target image back into the reticle circle. The arrangement of the mirrors is such that the sight case must be offset ahead of the target in order to center the image. This causes the sight case axis to lead the target by the necessary amount of lead angle. In a similar manner, the introduction of spots deflects the target image and necessitates a change in the lead angle.

In those modifications of the sight which incorporate provisions for radar tracking, a cathode-ray tube is installed in the sight case. The radar image is reflected from a mirror to a pellicle in the optical axis of the telescope. This pellicle is a very thin plastic sheet which is semi-transparent, so that it reflects the radar image through the reticle plate to the telescope eyepiece, but still allows the optical target image to pass through for optical tracking. In radar tracking, the optical target image is blocked out by increasing the density of the optical filter; the intensity is turned up on the radar scope; and the radar image (a bright spot) is kept centered in the reticle.

When the Mark 15 sight is used in conjunction with a radar, the radar antenna must be caused to lag the motion of the gun bore, in order to remain on target when the gun is offset by the computed lead angle. This is accomplished by providing a separate power drive for the antenna. Electrical signals originating in the gyro pick-off transformers and defining the magnitude and direction of the lead angles are used to control the antenna power drive. In some cases, the radar antenna is mounted on the director, while in other cases it is located on the gun mount. The electrical signals from the pick-off transformers actuate the radar antenna power drive to offset the antenna by the amount of the computed lead angle, but in the opposite direction from the target's motion. In bringing the antenna back on target, by centering the target image in the reticle, the sight case and the gun bore are offset ahead of the line of sight by the proper lead angles. Thus, when the radar target image is centered in the reticle circle, the gun will be properly positioned to fire at the target.

26C4. Operation

In preparing Gun Sight Mark 15 for operation, the unit must first be warmed up. The warming-up process requires a period of about 30 minutes for bringing the damping fluid to its operating temperature and viscosity. Bringing the gyros up to their designed operating speed requires about 6 minutes. When operating in an area where attack is likely, the sights are kept warmed up and ready for use.

Preliminary to firing, the target is located by means of a fixed auxiliary telescope mounted on top of the sight. The target is tracked briefly through the auxiliary telescope, after which the operator shifts to the gun-sight telescope. During this initial process the range is kept set at the minimum value in order to restrict movement of the gyro, or, if gyro cagers are installed, the gyros are kept caged. When the target image has been centered in the reticle circle, the cager is released and the proper range and range rate are set in. A similar process is used for radar tracking, except that in this case the auxiliary telescope cannot be used.

Tracking the target or radar spot is continued. The target or spot is kept centered in the reticle circle by smooth movement of the director. It is essential that all tracking movements be smooth, since sudden movements cause the generation of false lead angles.

During tracking, the appropriate values of range and range rate are continually set into the sight. If no radar is provided, estimated ranges must be set in. In this case the range setter should determine whether the range is set correctly by observing the projectile tracers. For an incoming target, which is the usual case, the range should be set initially so that the tracers pass just behind or below the target. Tracers passing behind the target indicate that the lead angles are too small. This is the case when the range setting is less than the actual range, as a short range setting causes the restraining springs on the gyros to be stiff. It is readily apparent that, as the target approaches, the actual range will agree more closely with the set range, and the tracer stream will move toward the target. When the actual and set ranges are equal, the tracers should be hitting the target. As the actual range becomes less than the set range, the tracers will pass ahead of the target, because the generated lead angles are too large. Now the range setting must be decreased to make the tracers again pass behind the target. Thus the range setting procedure is as follows:

1. Set range so that tracers pass just behind or below target.
2. Wait for tracer stream to pass through target.
3. When tracers are passing ahead of target, decrease range setting and repeat steps 1 and 2.

D. Gun Fire Control System Mark 63

26D1. General description

Gun Fire Control System Mark 63 is manually operated and is designed to control the fire of 40-mm and 3″/50 guns against air targets at ranges from 800 to 7,000 yards. Range rate limits on later installations are plus 350 knots and minus 800 knots. Targets may be tracked either optically or by radar. The radar antenna is carried on the gun mount. The system uses a disturbed line of sight, meaning that while the sight housing and gun barrels are aimed at future target position, the optical line of sight and radar beam remain on the present target position. See figure 26D2.

The major units included in the system are:

1. Gun sight Mark 15 or Mark 29.
2. Director pedestal.
3. Antenna mount.
4. Radar equipment.
5. Wind transmitter.
6. Target acquisition unit (TACU).
7. Train parallax corrector (if guns are displaced sufficiently far from the director to require parallax correction).

26D2. Operation

A crew of six is required for operation. Topside personnel are the control officer, the director pointer, the director range setter, and the gun control talker. The target acquisition unit (TACU) operator and the radar operator are stationed below decks.

A Lead-Computing Sight Mark 15 or Mark 29, employing air-driven gyroscopic computing mechanisms, is mounted on a pedestal-type director. The director is swung manually by the director pointer in train and elevation. Tracking can be accomplished in two ways. If the target is visible, it is tracked by keeping the reflection of the target image centered on a fixed reticle in the optical telescope. This method is known as *optical tracking*. If the target is obscured, or in case of night firing, the director pointer tracks a radar target spot which is introduced into the optical line of sight by a train and elevation scope in the gun sight.

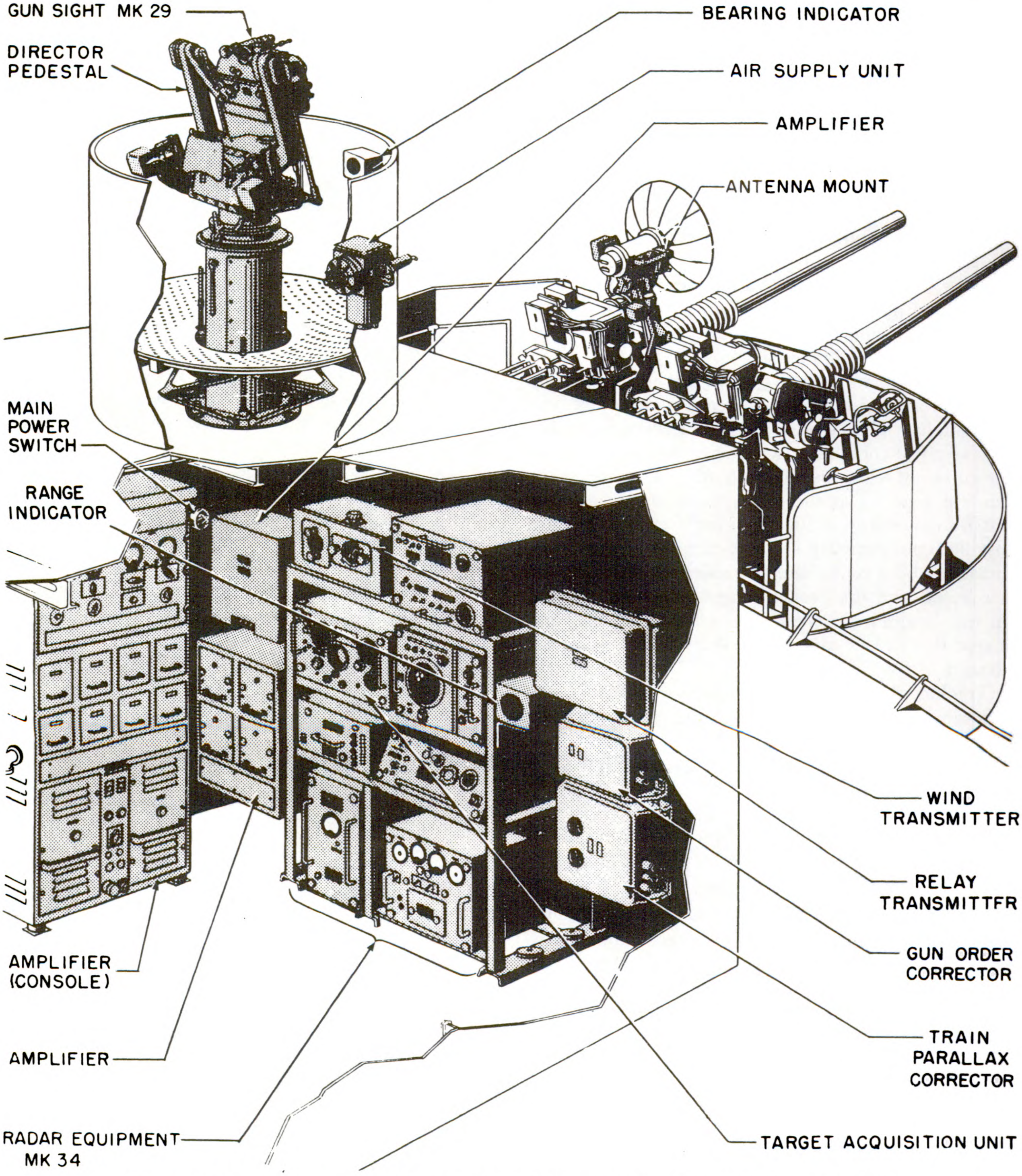


FIGURE 26D1.—Major units topside and below decks, Gun Fire Control System Mark 63.

This method is called *blind tracking*. When the target is sighted optically, the director pointer slews the director to get on, using an auxiliary telescope. A caging switch on the left handle of the director is pressed during this operation to prevent the gyros from generating a large false lead angle.

As quickly as possible after the target is picked up in the auxiliary telescope, the pointer shifts to the

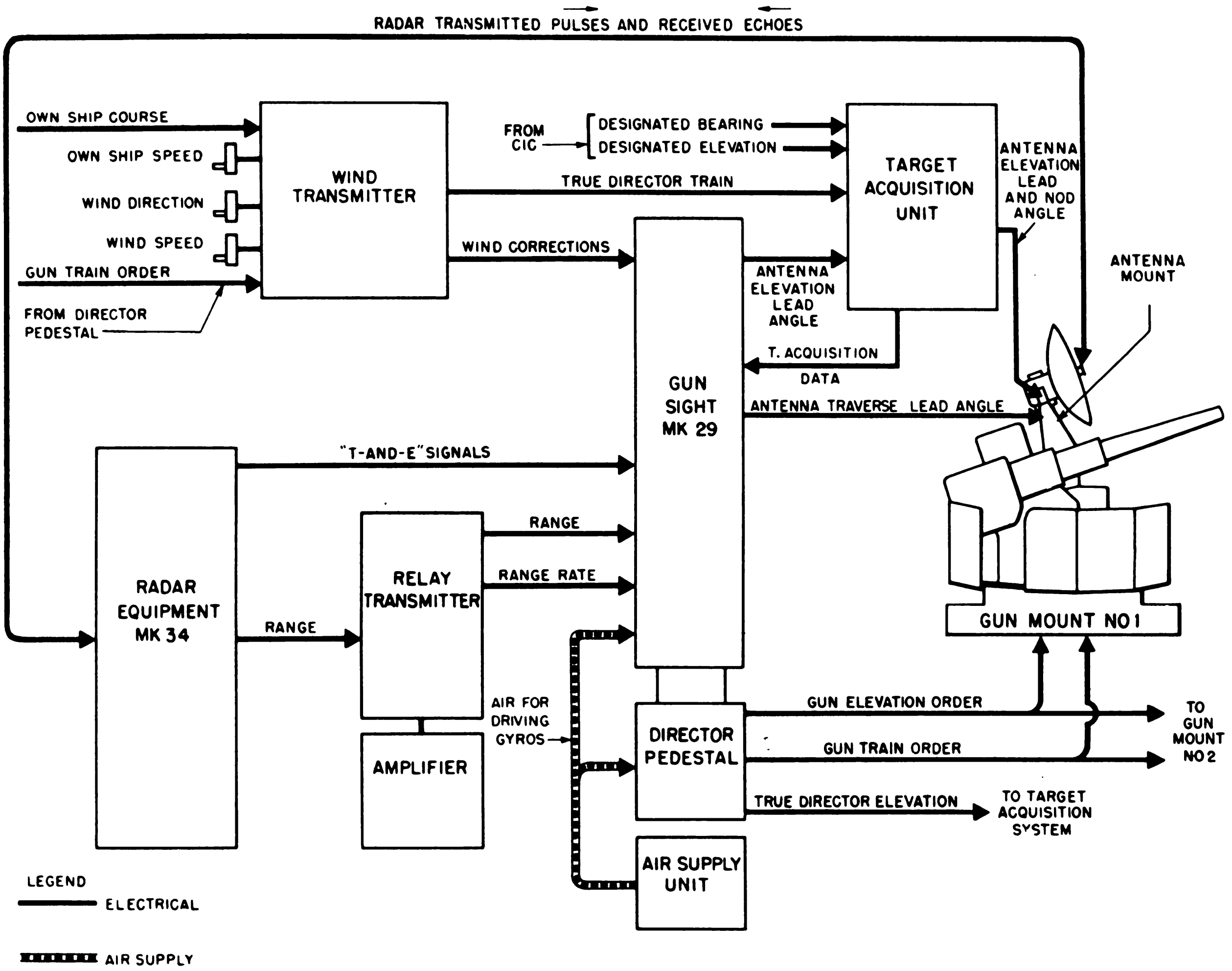


FIGURE 26D2.—GFCS Mark 63, simplified flow diagram.

tracking telescope of the gun sight and starts tracking smoothly, releasing the caging switch as the target is tracked. Corrective data from other units in the system (wind transmitter for wind corrections and radar for ranges and range rates) are transmitted to the director and applied as inputs to the gun sight automatically or by the range setter, who matches zero readers, thus sending these corrections into the gun sight. The corrections cause movement of the mirrors in the gun sight, changing the relative positions of the target image and reticle. The pointer, in maintaining the center of the reticle on the target, causes the director and the guns it controls to be offset from the line of sight and to point ahead of (lead) the target, because of movement of the mirrors in the optical system caused by precession of the gyros. The lead angle compensates for the relative motion of the target and for the effects of gravity, wind, drift, and spots, if any.

The lead angle is composed of two components: one in elevation, the other in train. The latter is corrected for horizontal parallax before being used at the gun, in installations where this refinement is warranted. The amount the director is offset from the LOS in elevation and train is continuously sent to the gun during tracking in the form of signals which control power drives at the gun.

26D3. Improved modifications

In later modifications of the Mark 63 system, the Mark 29 sight has replaced the Mark 15 sight, as it provides for handling greater target speeds. Also the Mark 1 Mod 0 director pedestal has replaced the Mark 51 director in later installations. The Mark 1 Mod 0 director pedestal incorporates one important feature not installed on the Mark 51 director, a cross-roll gyro. When the computer "cross rolls" or swings about the line of sight because of deck inclination, the elevation and train gyros tend to exchange functions. This exchange, however, is retarded somewhat by gyro damping. To compensate for errors caused by the damping, the cross-roll gyro measures cross roll directly and

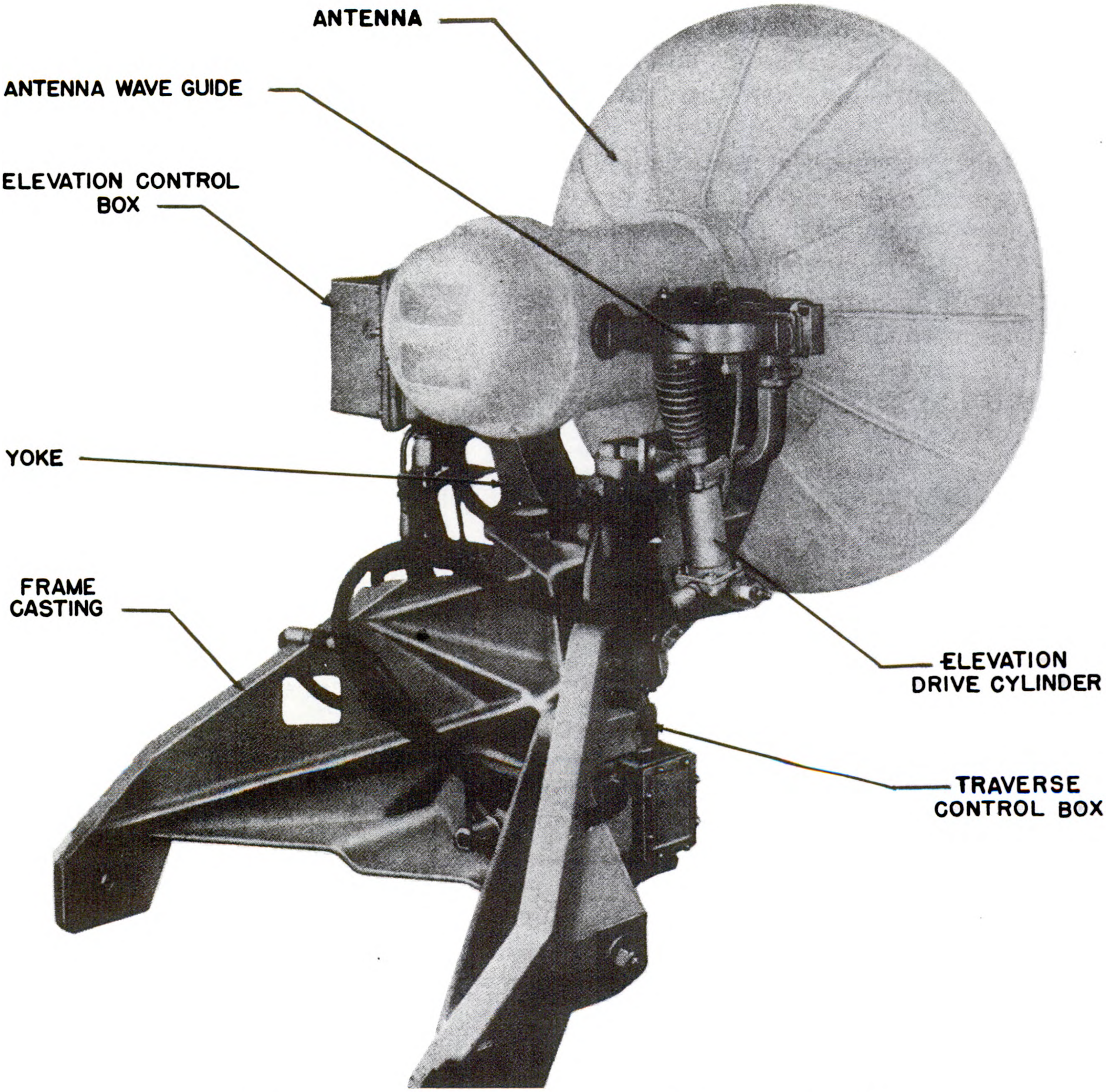


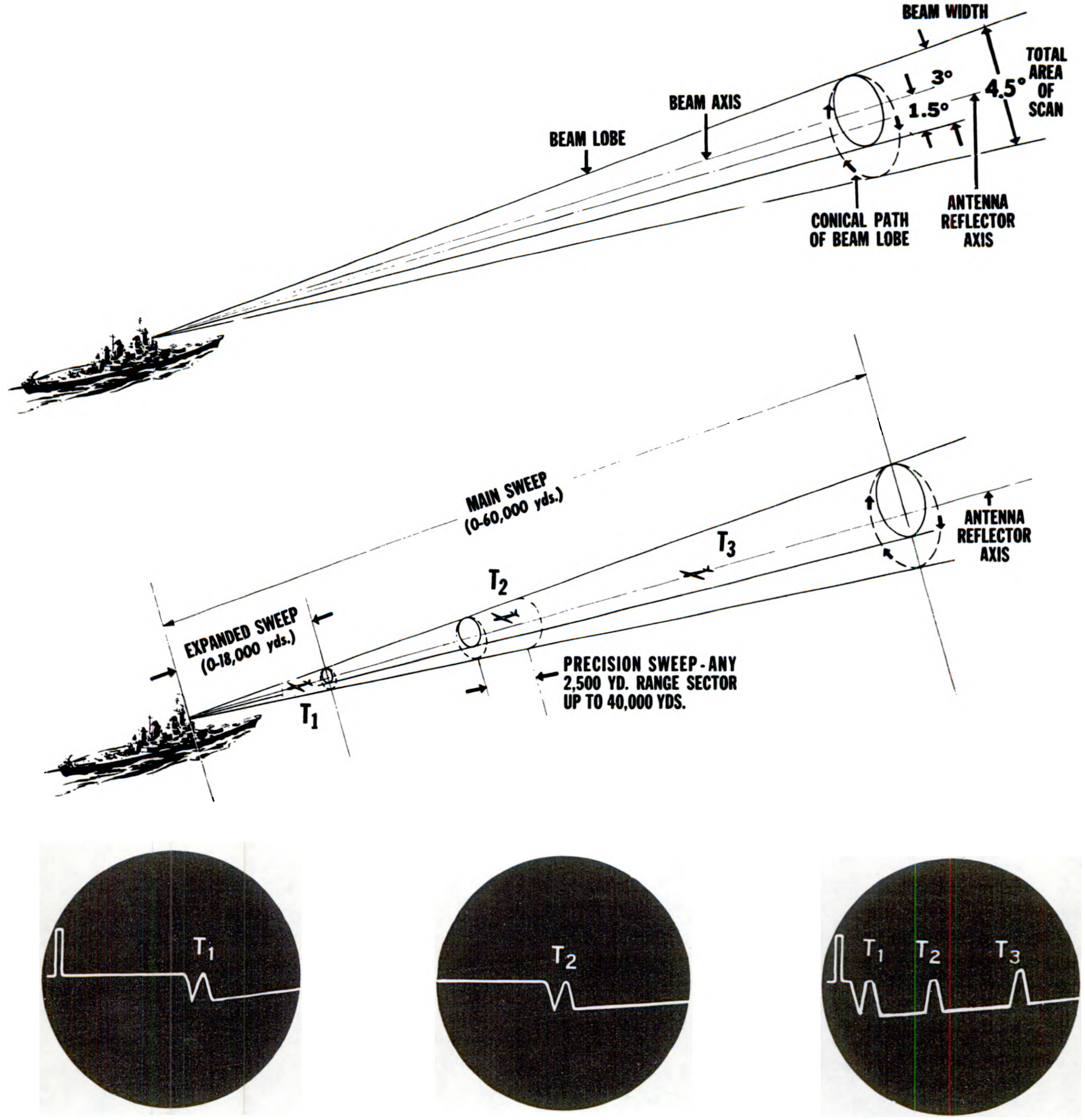
FIGURE 26D3.—Antenna mount (with antenna assembly), GFCS Mark 63.

modifies the output of the sight accordingly by means of cross-roll torque motors on the gyro output shafts in the Mark 29 sight.

26D4. Radar equipment

The earliest Mark 63 systems used Radar Equipment Mark 28, while all others use the Mark 34, which will be described. The Mark 34 radar sends to the gun sight values of range and range rate which are used in computing lead angles both in full and in partial radar control. In addition, the radar provides target-position signals for blind tracking. In blind tracking, as in optical tracking, the director is positioned manually, but the radar equipment aids the director pointer by locating an obscured target initially by means of the TACU unit, and by providing a target indication in the sight as a spot in the scope which can then be tracked, once the radar beam has been placed on the target.

As shown in figures 26D1 and 26D3, the radar antenna is mounted in a gimbal above the gun trunnions on the mount. Sufficient angular displacement permits the antenna to be offset from the bore axis in accordance with the lead angles generated by the gun sight. The limits are about 30° in any direction. This feature is necessitated by the fact that the antenna is mounted on the gun, which, of course, is laid for a predicted target position by the lead angles generated by the sight. The radar beam must remain at present target position. Signals positioning the guns are sent from the director to the guns. Lead angle signals are sent to the radar antenna drive, but in the opposite


BEAM WIDTH
TOTAL AREA OF SCAN
3°
4.5°
1.5°
BEAM AXIS
BEAM LOBE
CONICAL PATH OF BEAM LOBE
ANTENNA REFLECTOR AXIS
MAIN SWEEP (0-60,000 yds.)
T_3
T_2
EXPANDED SWEEP (0-18,000 yds.)
T_1
PRECISION SWEEP-ANY 2,500 YD. RANGE SECTOR UP TO 40,000 YDS.
ANTENNA REFLECTOR AXIS
T_1
T_2
T_1
T_2
T_3

RANGE UNIT
EXPANDED SWEEP

RANGE UNIT
PRECISION SWEEP

RANGE UNIT
MAIN SWEEP

Figure 26D4.—Beam and sweep characteristics.

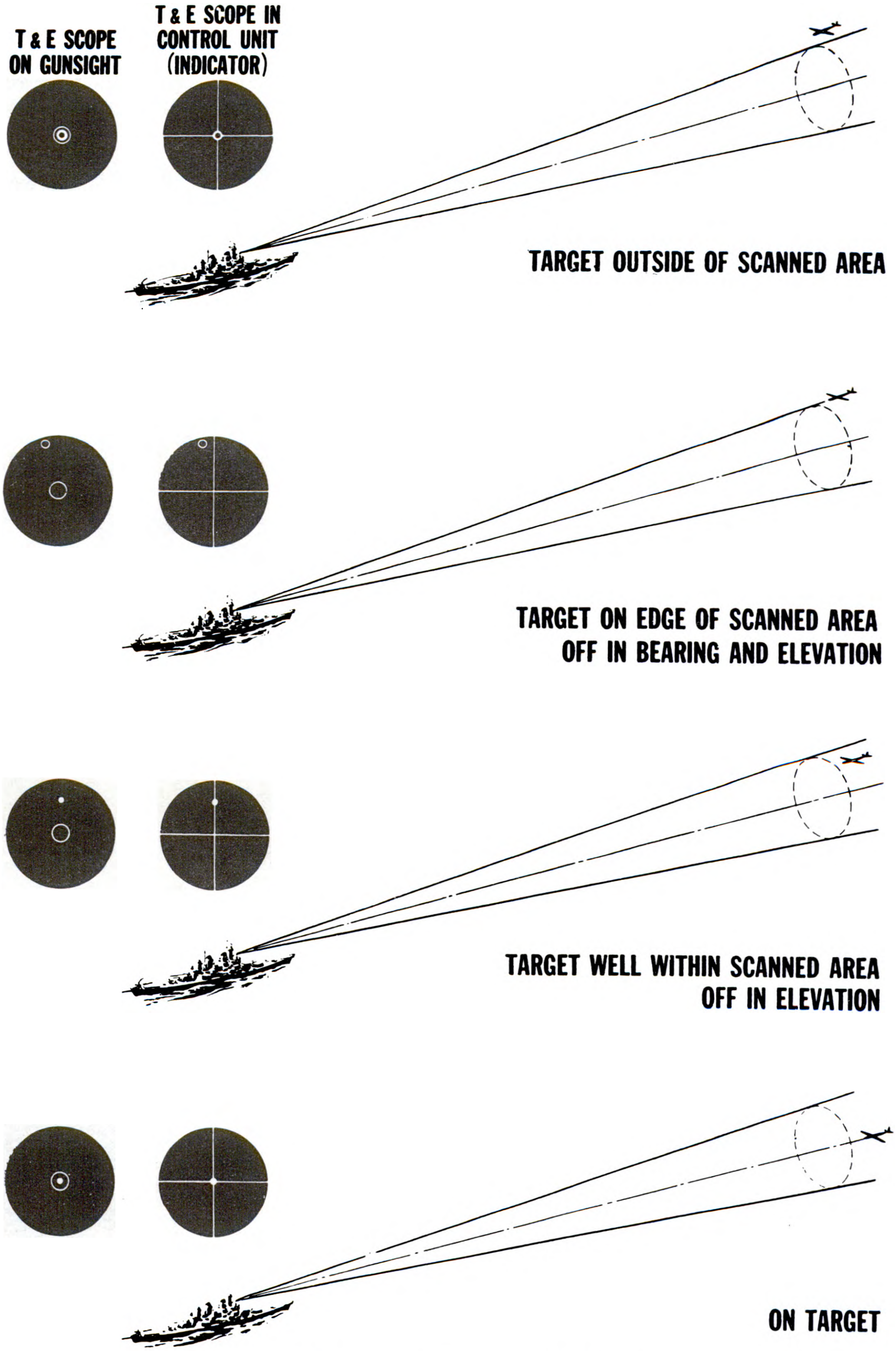

T & E SCOPE ON GUNSIGHT
T & E SCOPE IN CONTROL UNIT (INDICATOR)
TARGET OUTSIDE OF SCANNED AREA
TARGET ON EDGE OF SCANNED AREA OFF IN BEARING AND ELEVATION
TARGET WELL WITHIN SCANNED AREA OFF IN ELEVATION
ON TARGET

FIGURE 26D5.—Target indications on T&E-scope.

direction, to keep the antenna on the line of sight.

The antenna is a parabolic reflector with a feed line known as a *nutator* projecting from its center. A narrow conical beam of energy (approximately 3° wide) is radiated. By action of the nutator this beam is deflected 0.75° from the axis of the reflector and is rotated 30 cycles per second, thus providing a cone-shaped area of scan of 4.5 degrees.

26D5. Target acquisition

The target acquisition unit (TACU), which is a part of the Mark 34 radar, is located in the radar room. When visibility is poor, or when numerous targets are at the same approximate location, the TACU aids the director operator in acquiring the designated target. The TACU operator receives target information from an outside station, such as a search radar or a lookout, and can control the position of the TACU spot in the director pointer's train and elevation (T&E) scope to indicate the direction of movement necessary to point toward the designated target. If the target fails to appear in the TACU scope, the TACU operator can cause the antenna to nod in elevation at an angle of either ±15° or ±5° by a selector switch. Search in bearing can also be accomplished by throwing a switch which causes the spot to move back and forth across the T&E-scope. If the director pointer follows the spot, the TACU operator is enabled to scan a small bearing sector about the designated bearing. Close cooperation between TACU operator and director pointer is necessary to locate and get on a designated target. It should be noted that the spot used to coach the director pointer on the target is controlled by the TACU operator and is not the spot which appears on the pointer's scope once the target lies within the radar beam. Once the target has been picked up by radar, the TACU operator can determine range, bearing, and elevation data from a scope of the TACU.

26D6. Ranging

The radar operator, also stationed in the radar room, has two units which provide visual information about the target; namely, the control indicator and the range unit. On the control indicator, echoes from targets within the radar beam appear as pips along the horizontal sweep. The range-measuring indication is a sharp drop or *step* in the sweep line. When the step is set adjacent to the leading edge of a pip, a counter on the range unit shows the range in yards. By throwing a selector switch, a choice of three sweeps is possible as shown in figure 26D4. *Main sweep,* used for locating distant surface and air targets, shows all targets within the beam from 0 to 60,000 yards. The range crank moves the step to a maximum of 40,000 yards, beyond which target range must be estimated. *Expanded sweep* is accurate and is sufficient for most air targets, since it includes the firing range. It shows all targets from 0 to 18,000 yards, the range step again moving as the range crank is turned. *Precision sweep,* used for very accurate range measurement and tracking, covers any desired 2,500-yard sector of the entire measurable range (40,000 yards). In this case the step remains in the center of the sweep and the pips move along the trace as the crank is turned.

A small portion of the sweep—about 300 yards in range—is known as the *range gate.* The target is gated by turning the range crank on the range unit until the leading edge of the pip is adjacent to the sharp point at the base of the step. A drop in amplitude of all pips and grass along the sweep indicates that a target has been gated. Effective tracking can be accomplished only on gated targets, since no others will show up on the director pointer's T&E-scope. Targets may be tracked (kept gated) either manually by moving the range crank or by an aided tracking unit which causes the range step to move along automatically at a uniform rate. For fast-moving targets, the latter will give smoother tracking.

26D7. Operation in train and elevation

The scope on the control unit duplicates the image on the director pointer's T&E-scope. This train and elevation indicator permits the radar operator to work more closely with the director pointer.

The gun sight contains a T&E-scope for the information of the director pointer. Once the target is gated, the spot on the T&E-scope enables him to correct errors in the pointing, as shown in figure 26D5. Since the radar beam is being rotated, the target which is gated but not exactly on the center of the antenna axis will return a signal of different strength for each position of the radar beam. Such a target will give an image (spot) displaced from the center of the T&E-scope, and the direction of the spot from the center indicates the direction in which the antenna must be moved to center the spot. When the target is exactly on the axis of the antenna, the spot is in the center of a circular reticle. Keeping the spot so centered tracks the target.

The T&E-scopes give indications of signal strength as well as pointing error. A strong echo appears as a bright spot, weaker echoes as small rings increasing in size as the echo becomes weaker. When the echo is no longer present, a concentric "no signal" circle settles inside the circular reticle at the center of the scope.

The range accuracy of the Mark 34 radar is within 15 yards ±0.1 percent of the measured range, and the pointing accuracy is within 1 mil.

E. Gun Fire Control System Mark 56

26E1. General

Gun Fire Control System Mark 56, like other ordnance equipments, is constantly being improved. Thus the following discussion may not reflect current installations in every detail. General operating principles of Mark 56 systems are the same for all equipments; but the latest publications, instructions, and notices should be consulted.

Gun Fire Control System Mark 56, illustrated in figure 26E1, is an intermediate-range antiaircraft fire control system. Designed for use against high-speed subsonic aircraft targets, it provides gun train, gun elevation, and fuze orders for 3-, 5- and 6-inch guns. It may also be used against surface targets.

Where a ship has two batteries (of different calibers) capable of AA fire, the system can produce different gun orders for both batteries simultaneously, thus permitting both to fire on the same target. This variation is known as a dual-ballistic system.

The system incorporates:

1. Automatic radar tracking in bearing, elevation, and range, as accurate as the best optical tracking.
2. Remote control of the entire system from the control room below decks, which provides for rapid radar acquisition of obscured targets and for blind firing. Solution time of this system is relatively short (2 seconds), so firing can begin early in tracking.

The system consists essentially of a two-axis, power-driven, direct-line-of-sight director located above decks, and various computing units located in a control room below decks. Complete radar equipment is included as an integral part of the system. The radar antenna is mounted on the director, and all radar indicators are in the control room.

The system is operated by a crew of four men, including the control officer. The latter and the pointer are stationed in the director for optical acquisition and the tracking of visible targets, and the two other men are at a console in the control room. On the console are all radar indicators and operational controls for handling range and positioning the director. Acquisition of obscured targets is accomplished from the console by matching designating dials.

Director line of sight (including radar antenna) is stabilized by a gyro unit in the director. Computation of lead angles is based on director angular rates of motion in stabilized coordinates.

The discussion to follow presents first a general treatment of the fire control problem as solved by the system, then a detailed description of system components and operational controls.

26E2. Target positioning by the Mark 56 System

Figure 26E2 shows some of the space relations used in the Mark 56 system. The angular velocity of the LOS can be resolved into angular rates in two planes, elevation and traverse, dE and dBs. In the GFCS Mark 56, these rates are measured by the rate gyro, which is stabilized and hence measures the rates in the true elevation and the true traverse plane.

The solution, however, requires the use of linear rates of target motion, in a plane perpendicular to the line of sight at target's position. This plane is called the cross-traverse plane, and contains RdE and $RdBs$. Since the target is not moving entirely in the cross-traverse plane, the range changes at the rate dR, measured along the line of sight. RdE, $RdBs$, and dR, then, are the three basic linear rates of target motion.

The first step in the solution of the problem by the Mark 56 is the determination of target position. Target bearing and elevation are measured by the director. As the target is tracked, director train, $B'r'$ and director elevation $E'b$ are measured and transmitted by the synchros; electrical signals representing these angles are transmitted continuously to the computer. Target range (R) is measured by gating the target pip on the radar indicator. The range signal is transmitted automatically from the radar equipment to the computer.

Tracking the target is accomplished either optically or by radar. For optical tracking, a hand-grip type of tracking control unit and a telescope are provided on the director. Rotation of the hand grips generates electrical signals that control the director power drives in elevation and train.

In automatic radar tracking, the tracking signals originate in the automatic tracking circuits of the radar equipment. These error signals vary with deviation of the target from the center of the radar beam when in conical scan. Automatic tracking is accurate within one-half mil.

The director line of sight is stabilized by a gyro unit, located in a compartment at the rear of the director. The unit, shown schematically in figure 26E3, consists of a vertical gyro and a rate gyro. The gyroscope unit is mounted on pivots in the gyro compartment. The elevation linkage attached to the antenna elevating gear is used to tilt the gyro main (elevation) gimbal so as to maintain the gyro gimbal axes parallel to the line of sight.

The primary purpose of the vertical gyro is to establish a stable reference plane called the true traverse plane, as shown in figure 26E2. The vertical gyro, as shown in figure 26E4, also measures E, true elevation

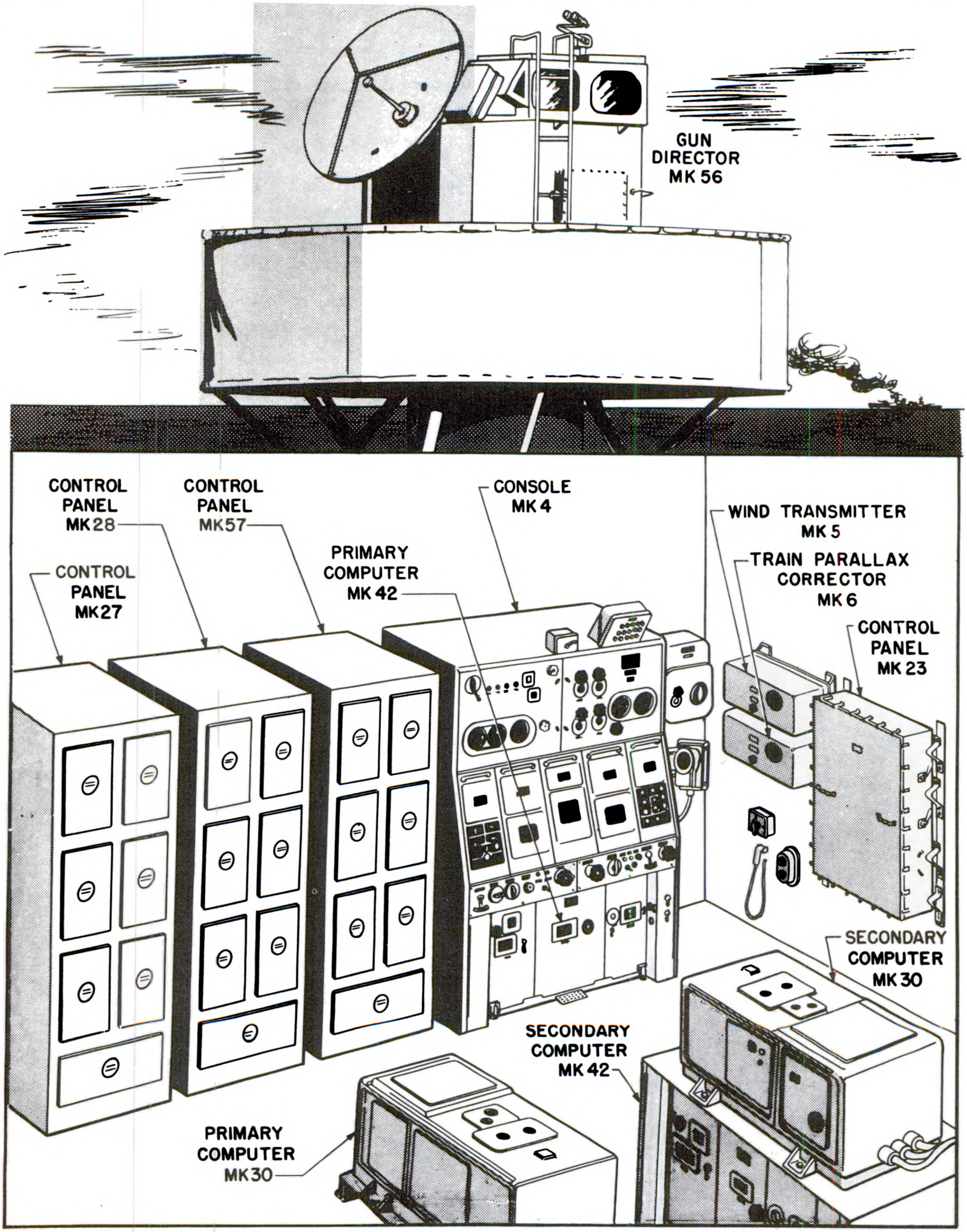


FIGURE 26E1.—Components of Gun Fire Control System Mark 56.

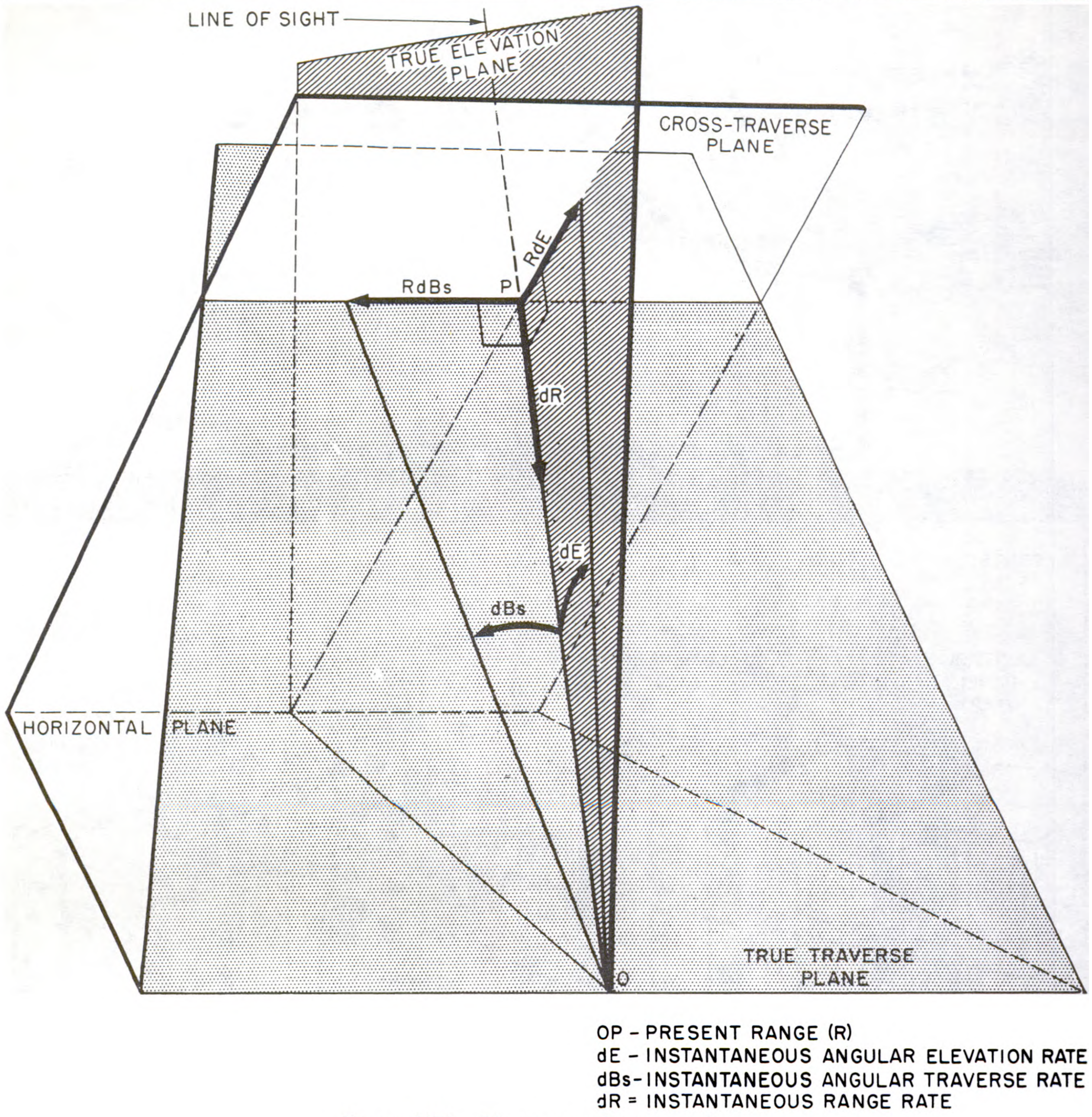


FIGURE 26E2.—Linear rates of target motion.

of the director line of sight above the horizontal, and *Zs,* cross-traverse angle. Like crosslevel, cross traverse is motion about the line of sight due to movement of the deck. However, cross traverse is measured in the cross-traverse plane, which is perpendicular to the line of sight, and therefore differs from crosslevel. The values of *E* and *Zs* are picked off by elevation and cross-traverse control transformers and are transmitted to the computer, where they are applied in calculating ballistic corrections and gun orders. *Zs* also goes to the cross-traverse drive gear of the rate gyro.

The rate gyro, shown in figure 26E5, controls the drive motors which position the director in train and elevation. The gyro does this by measuring the angular rates of target motion in the form of electrical tracking signals and combining these signals with the stabilizing signals *E* and *Zs* from the vertical gyro. The algebraic sum of these signals is obtained in a set of pick-off coils called a crossed-E transformer and shown in figure 26E5. The crossed-E transformer is composed of five coils arranged to form a cross with axes at right angles. The center coil is energized by

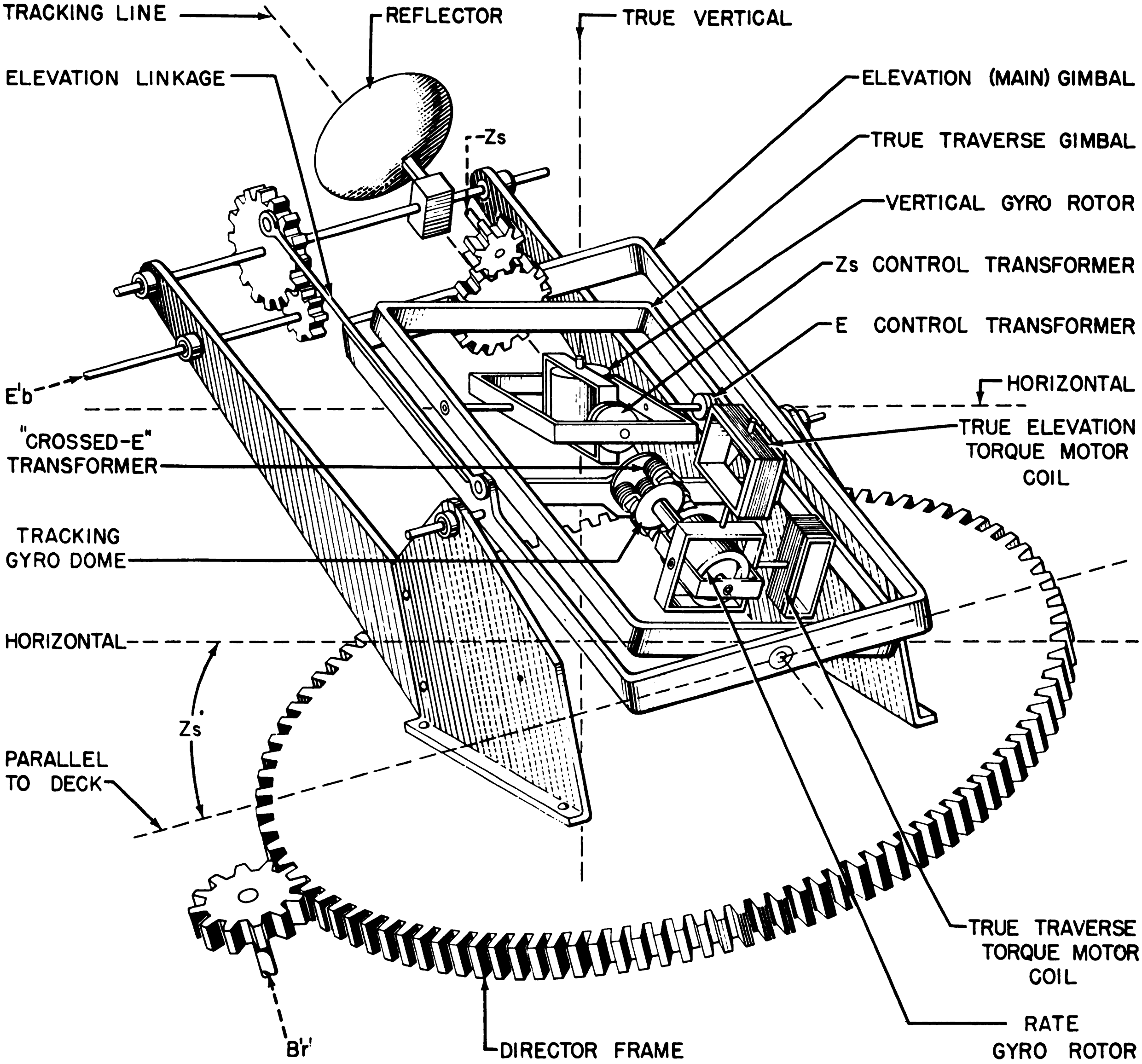


Figure 26E3.—Gyro system schematic.

100 volts, alternating current. This voltage induces voltages in the other coils. Supported by the vertical frame, coils are kept oriented in the vertical plane through the tracking line, as shown in figure 26E3, and are connected in phase opposition. The other two coils are oriented in the true traverse plane. Carried on the rate gyro shaft is the reluctance dome.

When the rate gyro is positioned with its center over the center coil of the crossed-E transformer, the air space between the dome and the transformer coils is the same, and the voltages induced in the coils on opposite sides of the transformer are the same, but opposite in phase. Consequently, the output is zero. When the dome moves off center, the voltages in opposite coils become unequal and error signals in elevation and traverse are generated. This operation is similar to that of the umbrella and magnet in the stable vertical.

The error signals in elevation and traverse form part of the input to the director drive motors. In this manner, the director is driven to stay on the target, even though the ship is rolling and pitching.

26E3. Measuring rates of target motion

If the director remains on target continuously, the angular rates of director motion are the same as the

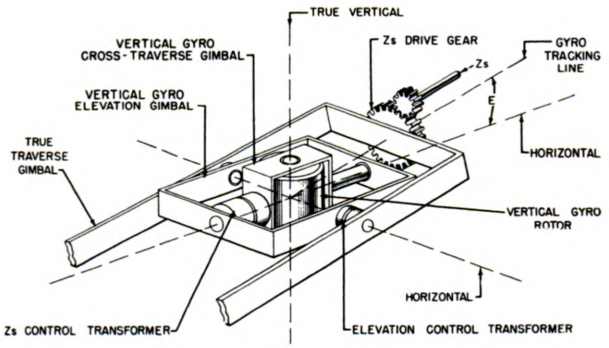


FIGURE 26E4.—Vertical gyro.

angular rates of relative target motion. Therefore, the train and elevation tracking signals are transmitted to the computer as rates of target motion, *dE* in elevation and *dBs* in traverse.

In obtaining these rates of target motion, the property of gyroscopic stability is used. As the director tracks the target, the rate gyro tends to lag behind, causing the radar antenna and the optical telescopes to lag. The need for correction becomes obvious to an optical tracker, who gets back on the target by handwheel motion, thus correcting the error. With automatic radar tracking, error signals are introduced electronically. In either type of tracking, the error signals generated go to the elevation and traverse torque motors shown in figure 26E5. The gyro is precessed to follow the target, but this is only the first step in repositioning the director. In addition, the reluctance dome carried by the gyro is moved off center when the gyro is precessed. Voltages are induced in the coils of the crossed-E transformer, and these voltages are used to drive the director in train and the antenna in elevation until the director line of sight is back on the target.

The crossed-E transformer receives error signals due to tracking rates and also stabilizing signals produced when the antenna moves off the target because of deck inclination. The two are continuously combined, and the director is driven to correct for both effects.

Also required in computing lead angles is range rate *dR*, which is obtained from a tachometer attached to the shaft of the range servo motor. The tachometer is a small generator whose output voltage varies with speed of rotation. The output voltage is therefore a measure of the rate at which the range motor is rotating, in other words the rate of change of present range.

From the three rates of target motion, *dE, dBs,* and *dR,* the computer calculates lead angles in true traverse and true elevation to account for movement of the target during time of flight.

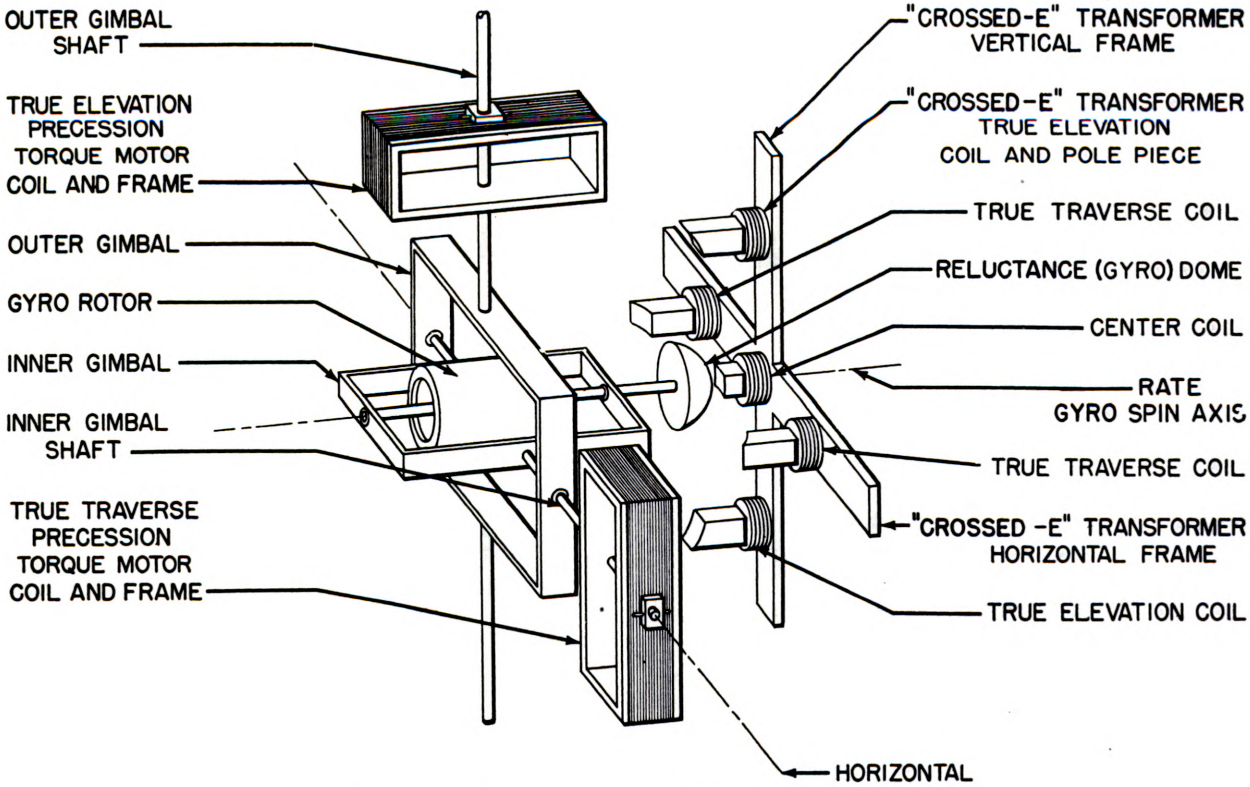

OUTER GIMBAL SHAFT
TRUE ELEVATION PRECESSION TORQUE MOTOR COIL AND FRAME
OUTER GIMBAL
GYRO ROTOR
INNER GIMBAL
INNER GIMBAL SHAFT
TRUE TRAVERSE PRECESSION TORQUE MOTOR COIL AND FRAME
"CROSSED-E" TRANSFORMER VERTICAL FRAME
"CROSSED-E" TRANSFORMER TRUE ELEVATION COIL AND POLE PIECE
TRUE TRAVERSE COIL
RELUCTANCE (GYRO) DOME
CENTER COIL
RATE GYRO SPIN AXIS
TRUE TRAVERSE COIL
"CROSSED-E" TRANSFORMER HORIZONTAL FRAME
TRUE ELEVATION COIL
HORIZONTAL

FIGURE 26E5.—Rate gyro and crossed-E transformer.

26E4. Ballistic corrections

The computer consists of the following units: ballistic computer, wind transmitter, parallax corrector, and gun order converter, together with associated amplifiers. Computations are performed by a chain of electrical and mechanical networks distributed among these units. Because of physical distribution and intermingling of circuits, any of these units or all of them together may be considered as the computer.

On the basis of inputs of present target position and the rates of target motion, the computer calculates superelevation and drift. To correct for the effects of wind, the computer receives electrical values of own-ship course from the ship gyro compass and manually introduced values of true wind speed, true wind direction, and own ship's speed. Corrections are made for the effects of apparent wind upon projectile travel in elevation, traverse, and range.

The ballistic corrections in the Mark 56 system are computed in terms of rates. In accomplishing this the angular rates *dE* and *dBs* received from the director are first multiplied by *R* to give linear rates *RdE* and *RdBs*. Then corrections to the linear rates, *RdE*, *RdBs*, and *dR* are worked out for superelevation, wind, *etc.* For example, *RdBsf* is the correction to *RdBs* for drift, *RdBsw* for wind. The final corrected rates, shown in figure 26E6, become *RdBstfw, RdEtfpw,* and *dRtfw.* The *t* indicates relative target motion and the *p* a correction for vertical parallax.

Unlike other systems, the Mark 56 does not multiply the applicable linear rates by time of flight to obtain lead angles *V* and *D*. Instead, the rates are divided by average shell, velocity *U,* where $U=\frac{R2}{Tf}$. Basing the solution on *U,* the average velocity, gives more accurate predictions. The most accurate solution is obtained at a medium range, with accuracy decreasing to give maximum error at either a short range or maximum range. However, the maximum errors are so small they do not affect the accuracy of gunfire appreciably. With a chronograph operating in conjunction with the radar, very accurate values of *U* are obtained.

When *U* is not measured by chronograph, the computer must receive a manual input of initial velocity to correct for variations in projectile velocity caused by gun erosion, powder temperature, and atmospheric

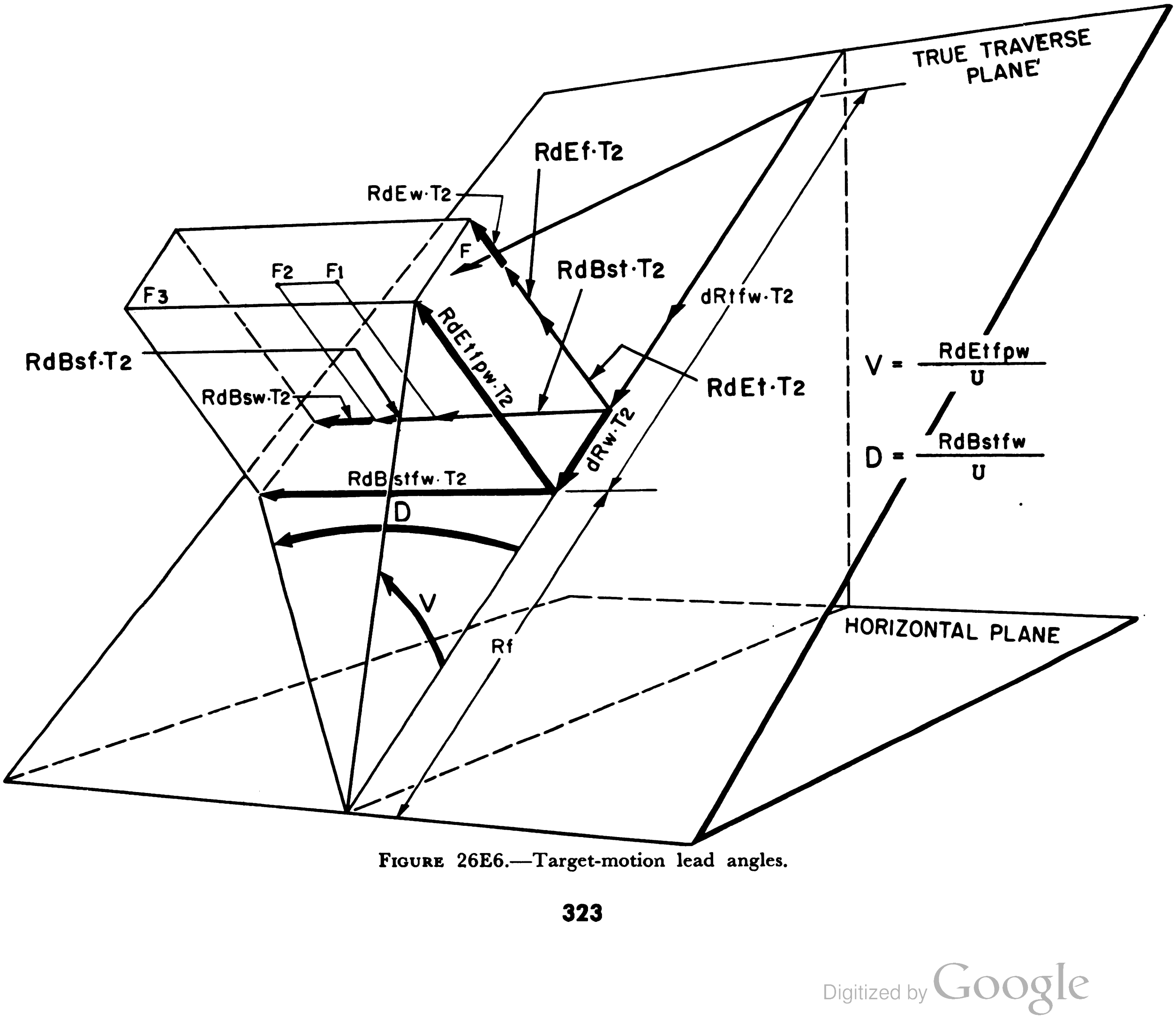


FIGURE 26E6.—Target-motion lead angles.

density. When the chronograph is used, the input is actual average velocity of the projectile in flight.

A manual input of dead time must also be introduced into the computer to compensate for the effect of gun-crew loading time upon fuze time order.

The lead angles V and D, shown in figure 26E6, are in the true elevation and true traverse planes. Since present target position is measured in deck coordinates, the lead angles must be converted into their equivalent angles in deck coordinates. This conversion is performed in the Mark 30 computer by a graphic device called the axis converter. The converter is a small dummy-gun arrangement which reproduces the actual conditions of the problem. The stabilized lead angles are set into the converter, and the correct values of lead angles in deck coordinates are continuously picked off and used in making up gun orders.

Parallax correction is accomplished in three parts: (1) an elevation correction to account for the vertical displacement of the gun mount from the director, (2) a correction to director train to correct for the fore-and-aft displacement of the director from the ship's reference point, (3) unit parallax correction (100-yard base length), which is transmitted to the gun mount, where a correction is made to gun order for displacement of gun mount from reference point.

26E5. Composition of gun orders

With the lead angles V and D in true coordinates converted to the deck-plane coordinates as $V'd$ and $D'd$ they can be added to $E'b$ and $B'r'$. Gun elevation order $E'g = E'b + V'd$ and gun train order, $B'gr = B'r' + D'd$. These values are transmitted to the guns, where a final correction for horizontal gun parallax is introduced into gun train order.

The fuze setting order (F) for mechanical time fuzes is computed in the Mark 42 computer.

26E6. Summary of system operation

Figure 26E7 shows the flow of basic quantities in the system when using automatic radar tracking, which is the usual method of operation. The radar equipment in the radar room receives target echoes from the antenna and transmits traverse and elevation error signals to the gyro unit as tracking signals and to the computer as rates of target motion. By resetting the control switches, signals from the optical tracking control unit in the director may be selected in place of radar error signals. The radar equipment transmits range and range rate to the computer during both radar and optical tracking.

In the gyro unit, tracking signals are added to stabilizing signals. The resultant signals control the director power drives. As the director tracks the target, director position is measured by synchros, and director train and elevation are transmitted to the computer. The gyro unit also transmits values of true director elevation and cross-traverse angle to the computer.

Own-ship course and speed are introduced to the computer electrically from the gyro compass and pitometer log, while true wind speed and direction, initial velocity, and dead time are introduced manually. The computer calculates lead angles and ballistic corrections, and makes up and transmits gun elevation order, gun train order, fuze time order, and unit parallax correction to the guns. Within two seconds of the start of steady tracking (either optical or radar), the computer is producing accurate gun orders.

26E7. System components

The components of a single-ballistic system of GFCS Mark 56, figures 26E1 and 26E7 are:

1. Gun Director Mark 56.
2. Radar Equipment Mark 35.
3. Console Mark 4.
4. Computer Mark 42 (ballistic computer).
5. Computer Mark 30 (gun-order converter).
6. Wind Transmitter Mark 5.
7. Train Parallax Corrector Mark 6.
8. Chronograph.
9. Bearing Indicator Mark 10.
10. Selector Switch Mark 13.
11. Control Panel Mark 23.
12. Control Panels Mark 27 and Mark 28.
13. Train and elevation amplidyne generators.
14. Motor-generator set.

In addition to these units, a dual-ballistics system requires for computing gun orders for the secondary ballistics:

15. Computer Mark 42.
16. Computer Mark 30.
17. Control Panel Mark 57.
18. Ballistics selector switch.
19. Secondary ballistics fuze control unit.

26E8. Components

1. Gun Director Mark 56, figure 26E8, is located above decks, in a position affording maximum visibility. Its primary function is to supply the computer with continuous present target position and rates of target motion.

The main body of the director is a shell of steel plate. A two-man director-operating crew is stationed in the left section, called the cockpit, with the control officer behind the pointer. In the cockpit are the tracking controls and various dials and switches used

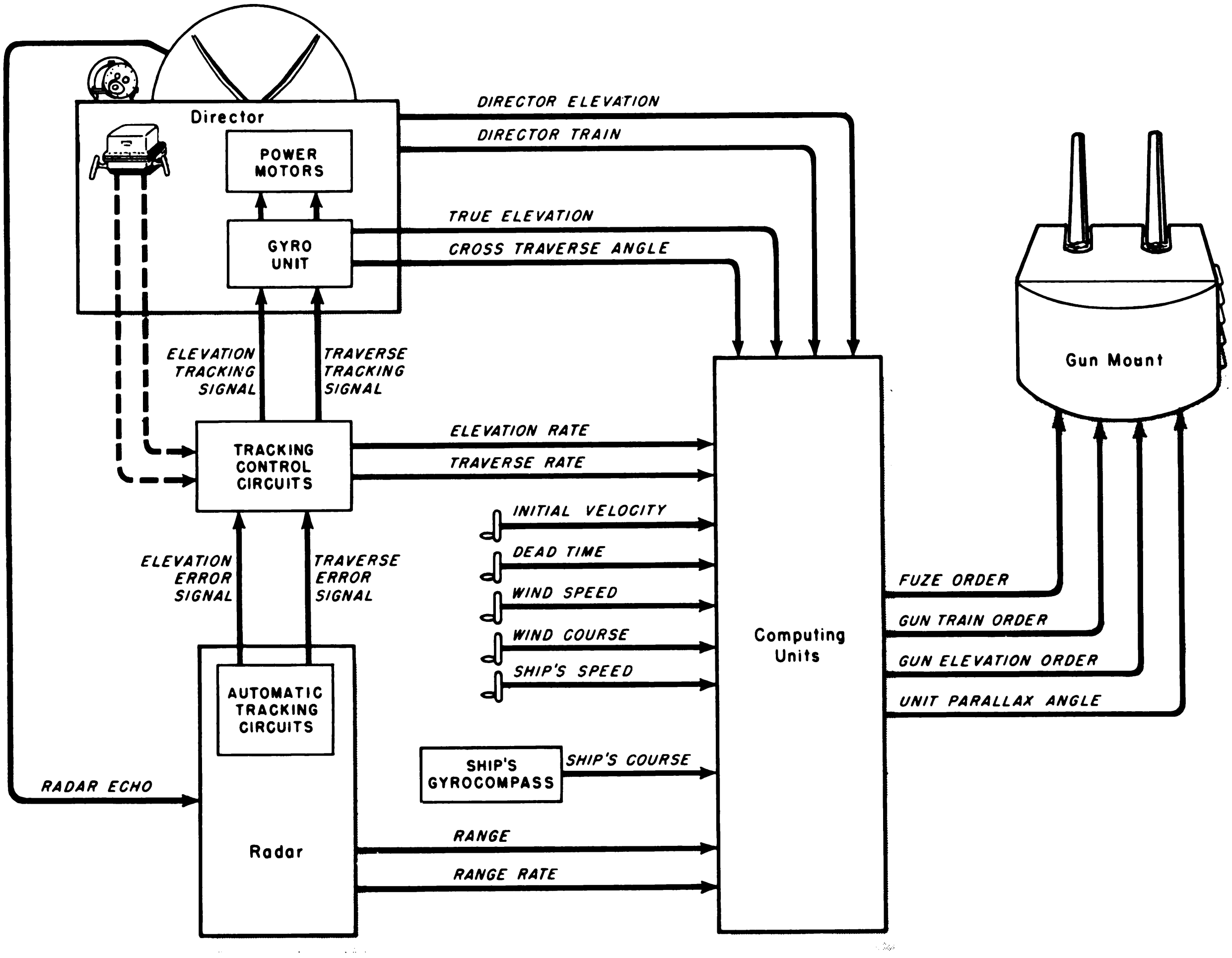


FIGURE 26E7.—Flow diagram of basic quantities, GFCS Mark 56.

to operate the system. The right section consists of four watertight compartments which house the gyro unit and various above-deck units of Radar Equipment Mark 35. Mounted on the main body are the sighting unit, telescope, tracking control unit, slewing control unit, and radar antenna.

The sighting unit consists of a vertical stand and elevating crossarm on which a binocular is mounted. The crossarm is geared to the director elevation transmitters and moves with the telescope line of sight in elevation. Operation of the sighting unit is controlled by the handgrips on the slewing control unit, which is similar to the tracking control unit. A trigger-type switch in the right handgrip of this unit allows the control officer to take slewing control of the director at any time from any other mode of control.

The pointer's tracking control unit is used for moving the director when tracking visible targets. This unit rotates about a vertical axis. The handgrips rotate about a horizontal shaft. Rotation about either axis generates an electrical signal that controls the director power motors.

The radar antenna assembly consists of a parabolic reflector, a nutating antenna feeder, and a scanning mechanism. The entire assembly, mounted on trunnions and connected to the director elevation gearing, elevates with the line of sight.

The antenna forms a beam of set width. The scanning mechanism nutates the beam in either conical or spiral scan. In conical scan, the beam nutates through a cone of set diameter. In spiral scan, the beam nutates in a spiral pattern, providing a coverage in baring and elevation.

The director is power-driven in train and elevation by d-c drive motors controlled by below-decks amplidyne generators. Movement in train is unlimited, because all electrical connections to the director are through a slip-ring assembly located at the base of the director. Movement of the director in elevation is limited by mechanical stops. Electrical limit

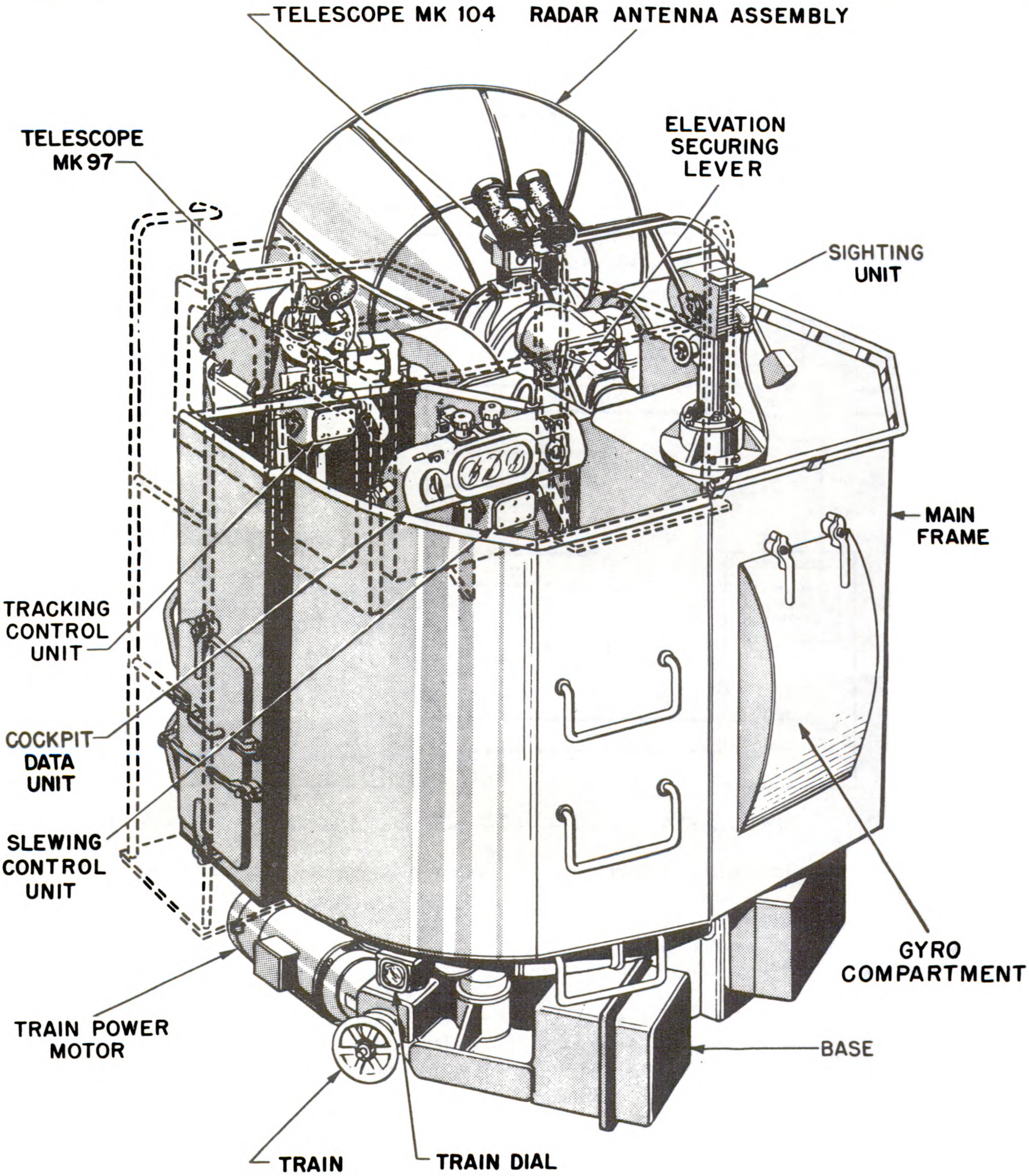


FIGURE 26E8.—Gun Director Mark 56.

switches cut out power to the drive motors before the mechanical limit stops are reached.

The director is provided with locks for securing in train and elevation when the director is not in use. Securing locks incorporate a protective micro switch that cuts out power to the amplidyne generators when either lock is in the secured position.

A train handwheel and an elevation handknob are provided so that the director may be moved for securing purposes when the power motors are off.

For transmitting values of train and elevation, the director is provided with synchro transmitters connected to the train and elevation drive-gear systems.

2. Radar Equipment Mark 35 supplies: (a) the computing units with continuous values of target range and range rates for both optical and radar tracking; and (b) the director with signal for tracking obscured targets. Once on target, the system will track automatically when radar control is being used.

Components of Radar Equipment Mark 35 located above decks are the antenna, scanning mechanism and motor, transmitter, and receiver. The radar indicators, range controls, adjustment controls, and automatic tracking circuits are located below decks on Console Mark 4.

3. Console Mark 4, figure 26E1, is the below-decks operational center. On it are the knobs, dials, and indicators necessary for below-decks operation of the system. While various phases of the computations are performed in separate computing units, inputs and power to these units are controlled from the console.

The console consists of four main sections: a dial section at the top, the radar section, the operational section, and Computer Mark 42 at the bottom. Bearing Indicator Mark 10 is mounted on the right side of the console.

On the face of the dial sections are knobs and dials for hand inputs to computing units; dials indicating range, elevation, and bearing; tracking-control indicating lamps; and a switch controlling computer operation.

The radar section consists of five panels containing the A/R-indicator, E-indicator, and B-indicator and switches for controlling radar operation.

The operational section contains the handknobs, slew levers, and switches for controlling the director in train and elevation, and for controlling range, antenna scan, and modes of operation.

4. Computer Mark 42, figure 26E9, is the ballistics computer. Its primary function is to compute pro-

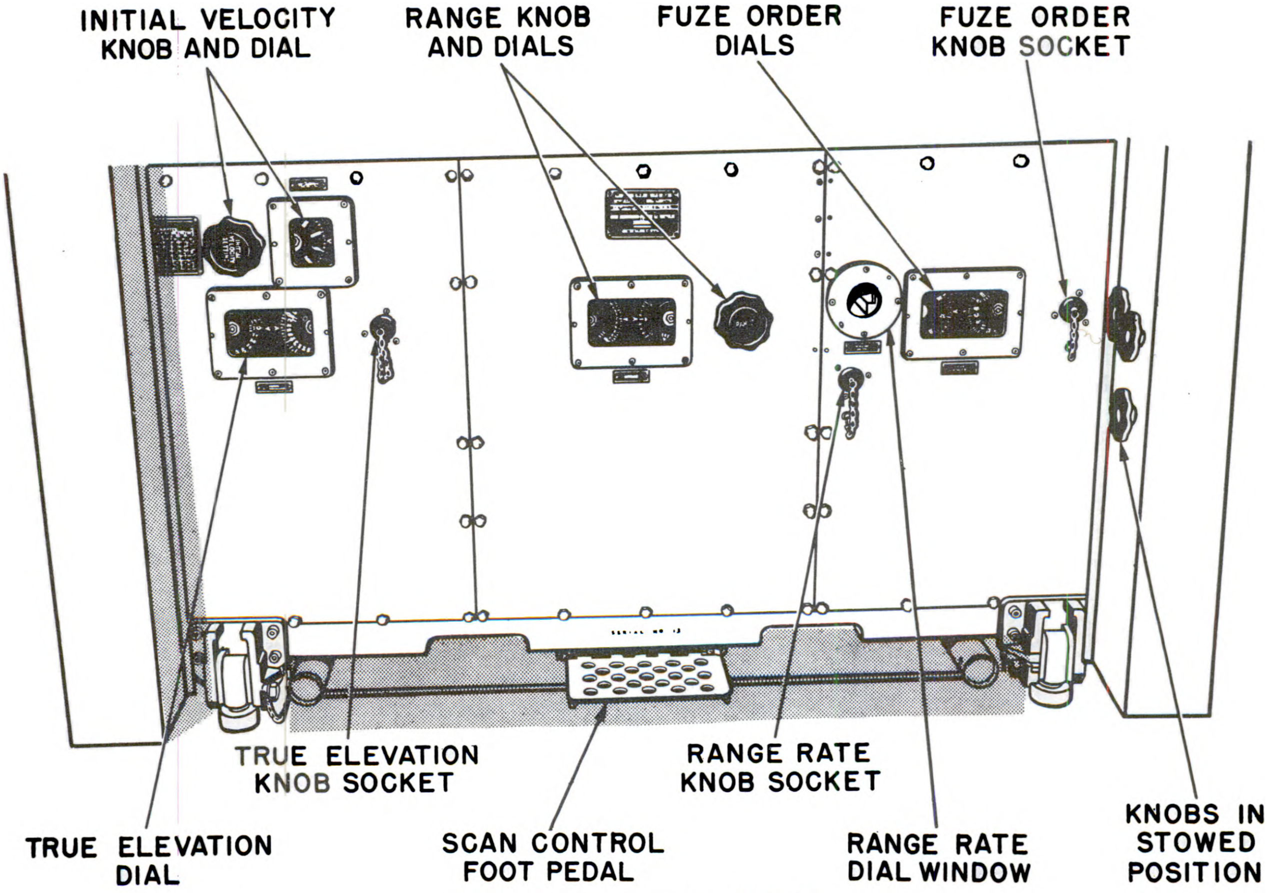


Figure 26E9.—Computer Mark 42.

jectile time of flight, superelevation, drift, range rate, and fuze order.

Dials indicate I. V. setting, true elevation of the director, range input to the ballistic computer, range rate as computed by the ballistic computer, and fuze order being transmitted to the guns. Knobs are provided for setting these values manually when performing tests; however, for normal operation, the true-elevation, range-rate, and fuze-order knobs are removed from their sockets and stowed as shown in figure 26E9, and the range knob is disengaged. Only the initial velocity (I. V.) knob remains engaged.

The pedal below the center panel of the ballistic computer controls the type of antenna scan.

5. Computer Mark 30 is called the gun-order converter. Its basic function is to convert the rates of target motion in true coordinates into lead angles in deck coordinates, and combine them with director train and elevation to produce gun train and elevation orders.

Four dials indicate director elevation, director train corrected for parallax, gun train order, and gun elevation order. The input value of the cross-traverse angle is visible through a window.

6. Wind Transmitter Mark 5 computes corrections to compensate for the effect of wind on projectile flight, and transmits them to the gun-order converter for inclusion in the solution of the problem. Electrical inputs of wind direction, wind speed, and ship speed are received from the console. A dial on the face of the wind transmitter indicates the direction from which apparent wind is blowing.

7. Train Parallax Corrector Mark 6 computes a correction for the displacement of the gun mount from the director along the ship's fore-and-aft axis. It receives values of range, elevation, and director train. The outputs are: (a) director train corrected to the ship reference point which is transmitted to the gun-order converter; (b) unit parallax correction, which is transmitted to the gun for correcting the value of gun train order. A dial indicates the unit parallax correction.

8. The chronograph measures the average velocity of the projectile, so that I. V. may be determined accurately.

9. Bearing indicator Mark 10 indicates director bearing (both relative and true) to the below-decks operating crew.

10. Selector Switch Mark 13, also called the Computer Mark 1A switch, is installed only on ships where GFCS Mark 56 is to be connected with Computer Mark 1A for surface fire. In the COMPUTER MARK 1A position, the switch allows values of director train and range to be transmitted to Computer Mark 1A.

26E9. Dual-ballistics units

A dual-ballistics system tracks one target but computes two sets of gun orders for guns of different ballistics. For example, in a typical light-cruiser installation, GFCS Mark 56 computes gun orders for 3"/50 and 6"/47 guns.

The dual-ballistics system requires a second Computer Mark 42 for the secondary ballistics, using the same inputs as the primary ballistics computer, and a Computer Mark 30 which computes gun train order and gun elevation order for the secondary ballistics.

The ballistics selector switch controls power to the secondary ballistics-computing units. It has two positions: PRIMARY and BOTH. The secondary units are energized when this switch is in BOTH.

The secondary ballistics fuze control unit controls fuze orders for the secondary ballistics.

26E10. Control officer's station

The control officer has available the following operational controls:

1. *Telephone-selector switch.* This selects the telephone circuit or circuits the control officer wishes to use. To speak directly to the radar operator or gun captain, he turns this switch to LOCAL. To parallel the circuits, he turns it to BOTH. Normally he leaves it on AIR DEFENSE.

2. *Slewing control unit, sighting unit,* and *slew switch.* The control officer can slew the director in train and elevation at any time by pressing his slew switch. This will take control away from any other mode of tracking. The control officer slews the director by rotating the handgrips of the slewing control unit for elevation control and by rotating the head of this unit for train control. The target is followed by use of the binocular mounted on the sighting unit. The binocular is kept parallel to the line of sight by an elevation input to the crossarm. The left handgrip of the slewing control unit has a press-to-talk switch which is equivalent to the mouthpiece button of the sound-powered telephone.

3. *Radar-optical switch.* This switch selects the type of tracking when the slew switch is released. If the radar-optical switch is positioned on RADAR, the radar console controls the director power drives. When this switch is set on OPTICAL, the tracking control unit has control. Two small lights indicate the station in control. When the slew switch is closed, the control officer can still give control to one of the other stations by closing a precedence button on his handgrip. This causes a take-over buzzer to sound in either station, depending on the position of the radar-optical switch. The station at which the buzzer sounds can bypass the slew control by closing a take-

over switch, a button on the handgrip of the tracking control unit, and the scan control foot switch at the console. This feature enables the control officer to relinquish control to another station while still slewing the director. To regain slewing control, he must release the slew switch, thus disengaging the precedence switch, and then close the slew switch again.

4. *Cockpit data unit.* This unit contains the telephone selector switch, target designation lamp, radar range dial, director train and elevation dials, and radar-optical switch.

5. *Hand microphone.* This is used by the control officer to give orders to the gun crews.

6. *Cease-firing contact maker.* This is for communicating CEASE FIRING order to the gun crew.

26E11. Director operator's station

1. *Telescope Mark 97.* The director operator tracks a visible target by keeping the crosshairs of the telescope reticle on the target.

2. *Tracking control unit.* This unit is operative when the radar-optical switch is on OPTICAL and the slew switch is open; or when the slew switch is closed, precedence switch is closed, radar-optical switch is on OPTICAL, and director operator's take-over switch is closed.

Since tracking signals are used in the computer as the rates of target motion, smooth tracking is of primary importance to the computation of accurate gun orders. To help the director operator track smoothly, the tracking signals from the tracking control unit are fed through an aided tracking circuit. For an instant after the tracking rates are changed, the director moves at higher rates than called for by the target's motion. The result is that the line of sight hops closer to the traget and then settles down to the new rates.

A firing key with a safety lock is inset in the right-hand grip of the tracking control unit. To close the firing key, the director operator must first release this safety lock by pressing the lever to the left.

3. The *press-to-talk switch* is located on the left handgrip of the tracking control unit. It is the equivalent of a mouthpiece button on the sound-powered phones.

4. The *amplidyne power switch* controls power to the amplidyne generators which supply the director drive motors. The amplidynes will not start before the gyro READY lamp lights, or the securing locks are off.

5. The *cockpit illumination switch* controls dial illumination to the cockpit dial unit, standby range input unit, and telescope reticle lamp.

26E12. Radar operator's station

The radar operator has available the following operational controls (fig. 26E10):

1. *Radar indicators.* Two oscilloscopes, the A/R-scope and the E-scope, provide the radar operator with his "view" of the target.

The A/R-scope, figures 26E10 and 26E11, has a double-trace presentation. The lower trace (A-sweep) extends from 0 yards. The range mark is movable and can be set on the target pip. Scribe marks on the scope face indicate the graduations in yards. The upper trace (R-sweep) is the expansion of the A-sweep, 500 yards either side of the range mark. The range step remains fixed near the center of the R-sweep and coincides with the range mark. Echoes from stationary targets and the 1,000-yard markers (only one of which is visible at any time) move past the range step as the target pip is moved along the A-sweep.

The E-scope, figure 26E12, shows range (horizontally) in yards, and director true elevation (vertically) in degrees. The vertical width of the trace depends on the type of antenna scan. The range mark is a bright vertical line extending from top to bottom of the sweep. Target echoes are vertical lines in elevation. Two curved lines on the scope face furnish an indication of target altitude.

Although normal E-presentation is generally used, an expanded presentation is available by turning the elevation sweep switch to EXPANDED. Expanded sweep shows the same trace as normal, except that it is expanded in elevation and its center is fixed at the center of the scope. It gives no indication of director elevation.

2. The *range slew lever* is used for slewing the range mark to the target pip.

3. The *range control switch* is used to control the mode of range operation. The range input signal may come from:

a. Radar operator's range slew lever.
b. Radar tracker's range crank.
c. Automatic range-tracking circuit.
d. Range memory circuit ("coast" button).
e. Target designation station.

4. The *radar-optical switch* may be used by the radar operator to select the method of operation. This switch is connected in parallel with the control officer's radar-optical switch, so that either station may select the method of control.

5. The *elevation crank* controls director elevation and allows for finer control than the slew lever.

6. The *scan control switch,* which controls the type of antenna scan, is usually placed on the foot switch,

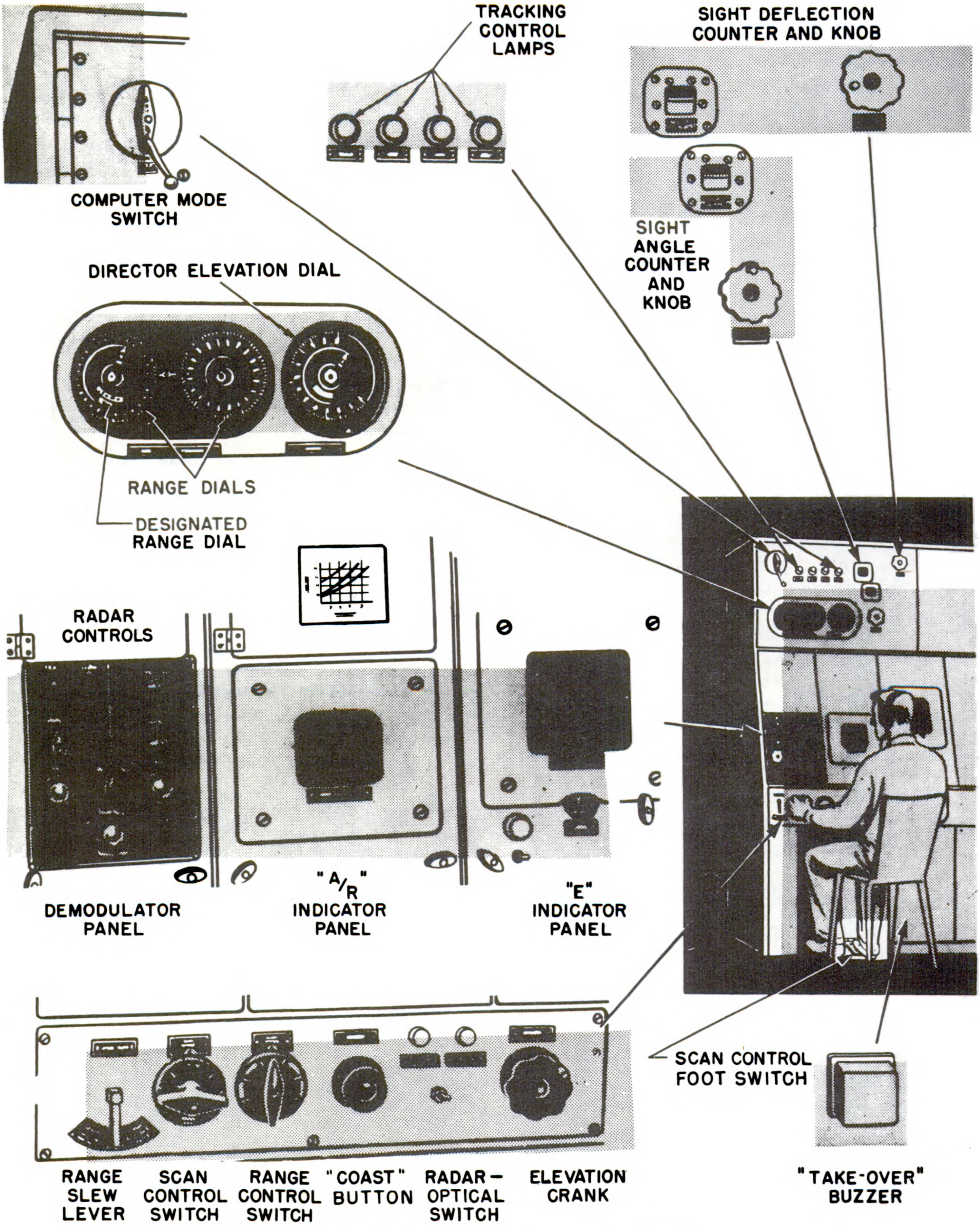


FIGURE 26E10.—Radar operator's operational controls.

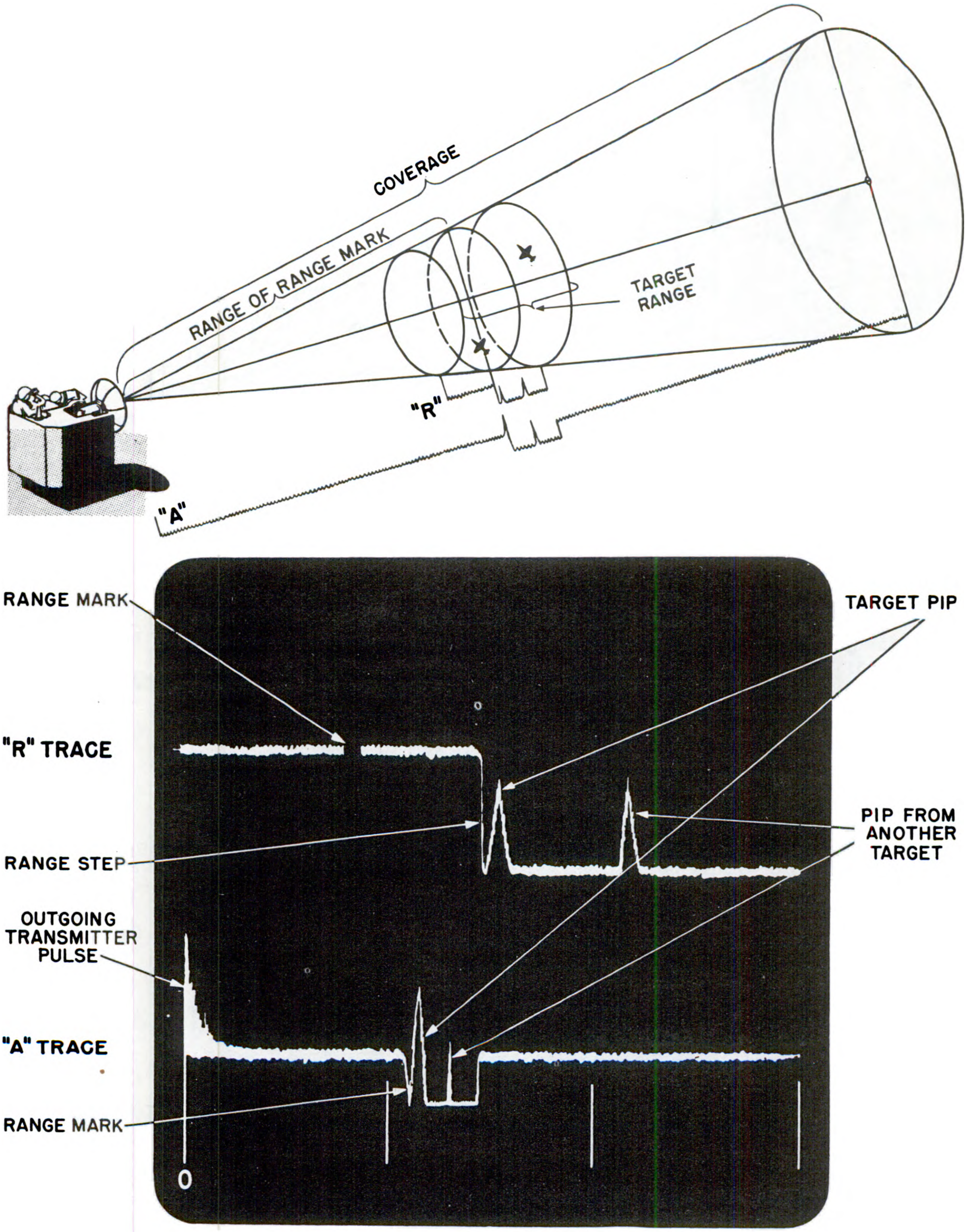


FIGURE 26E11.—A/R-scope presentation.

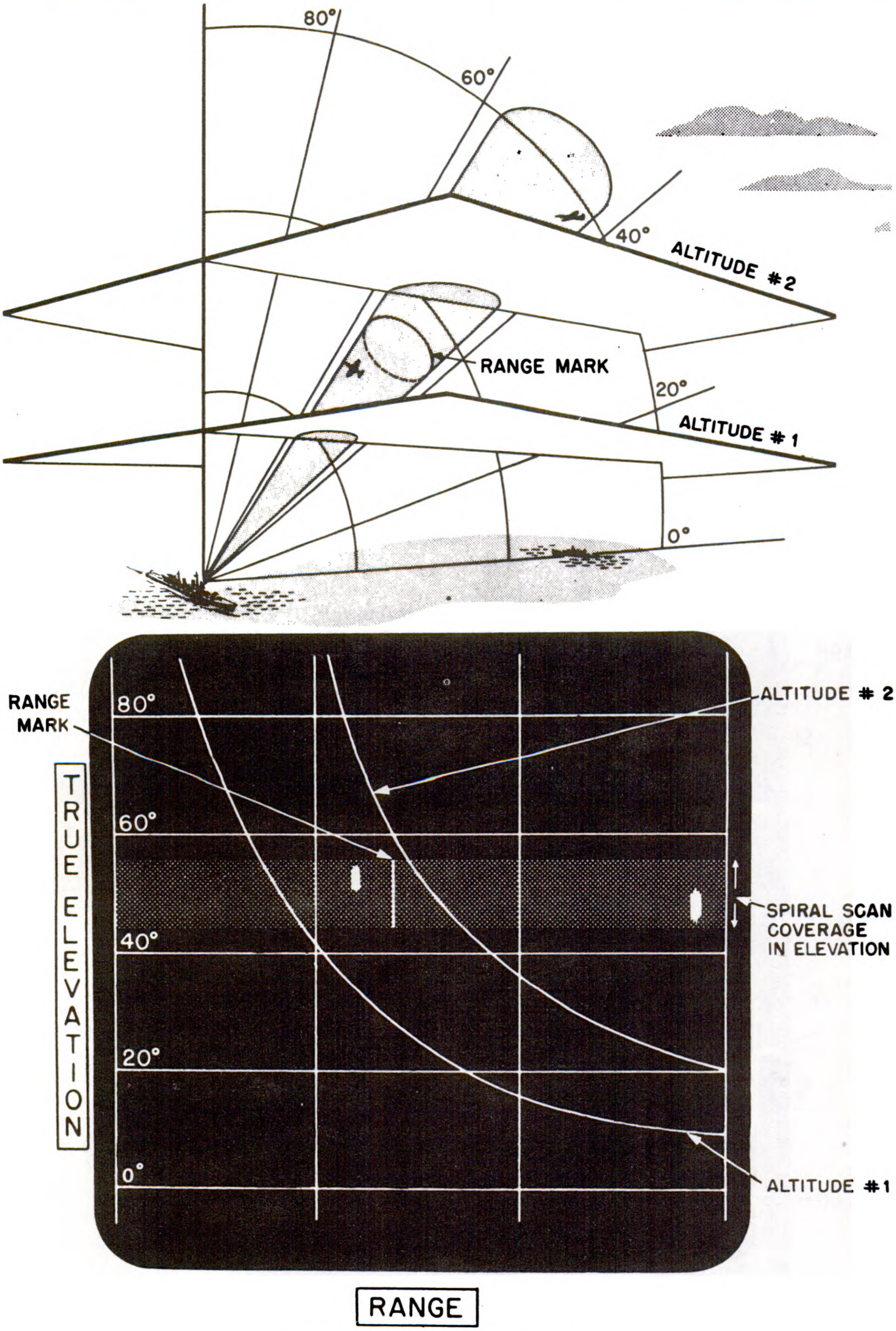


Figure 26E12.—E-scope presentation.

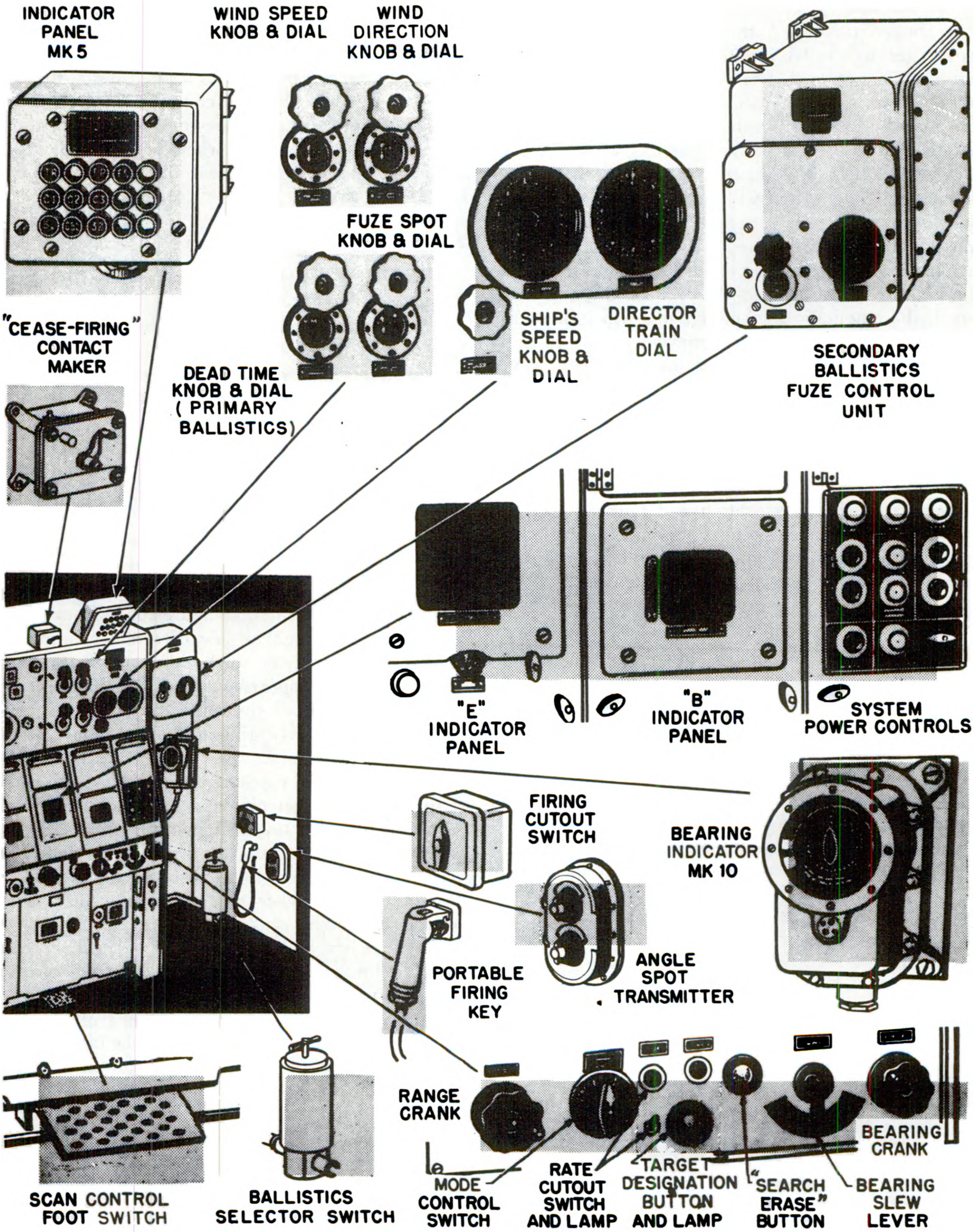


FIGURE 26E13.—Radar tracker's operational controls.

so that the scan control pedal can be used to select the type of scan.

7. The *coast push button* allows the system to "coast" through radar interference such as: (a) obscuring echoes from objects close to the target; or (b) radar "blind spots" caused by own-ship structure. This push button cuts out the automatic tracking circuits and substitutes the memory circuits, which maintain the existing rates of motion in traverse, elevation, and range. The system will coast at these rates for as long as the button is pressed, up to a maximum time of about two minutes. However, the button should be pressed only long enough for the target pip to clear the interference. When the button is released, the automatic tracking circuits will lock back on target pip if the beam is sufficiently close to the target; if not, the console operators must get back on target manually.

8. The *radar controls* are the knobs on the demodulater panel which control the operation of the radar equipment.

9. *Range and elevation dials.* The radar operator approximates director elevation and range from the normal E-scope presentation. For precise indications, he uses a fine and a coarse range dial, and an elevation dial which indicates elevation above the deck.

The range dials indicate the value of range being introduced into the computer (normally this is radar range). The designated range pointer indicates the value received from the target designation station.

10. The *computer mode switch* controls the mode of computer operation. On NORMAL, it allows the traverse and elevation tracking rates to be introduced into the computer as the rates of target motion.

On MANUAL INPUT, which is used for long-range surface fire (in which computer lead angles and ballistic corrections are not accurate), the computer does not calculate lead angles or ballistic corrections. Instead, it uses manually introduced values of sight angle and sight deflection as lead angles, combining them with director elevation and director train to produce gun orders.

11. The *target-designation lamp* located to the left of the tracking control lamps is lit when the radar tracker has pressed his target designation push button and the system is synchronized with signals received from the target designation station.

12. The *tracking control indicating lamps* indicate the setting of the tracking relays. The three lights are labeled· RADAR, SLEW SWITCH, and OPTICAL.

13. The *sight-angle* and *sight-deflection knobs* and *counters* are used during long-range surface firing when the computer is operating in manual input. The sight-deflection counter is calibrated in mils; its zero setting is 500. The sight-angle counter is calibrated in minutes; its zero setting is 2,000. For normal operation of the system, both counters are set to their zero settings.

14. The *take-over buzzer* is located inside the console and indicates that the control officer wants the console operators to take over control for radar tracking. This buzzer sounds when both the slew and precedence switches are closed and the radar-optical switch is on RADAR.

26E13. Radar tracker's station

The radar tracker has available the following operational controls, figure 26E13:

1. The system *power controls* are the various push buttons and indicating lamps with which the radar tracker controls power to the system. They are located on the console synchronizer panel to the right of the radar indicators.

2. *Radar indicators* are the radar tracker's "view" of the target, obtained from the E-scope and the B-scope. Since the B-scope covers a range interval of only 2,000 yards, the radar tracker, when searching for a target, watches the E-scope to help the radar operator spot the target pip. Otherwise he directs his attention exclusively to the B-scope.

The B-scope presentation, figure 26E14, shows bearing (horizontally) either side of director train, and range (vertically) 1,000 yards either side of the range mark. The trace appears as a vertical band, the center of which is always at the center of the scope. The width of the trace in bearing depends on antenna scan. The range mark appears as a horizontal line at the center of the scope, extending across the entire width of the trace. Target pips appear as horizontal lines of length equal to a few degrees of bearing.

For the pip to be visible on the B-scope, the range mark must be within 1,000 yards of the target pip. When the radar tracker sees the target in the B-scope, he turns the range crank to bring the pip up or down to the range line, and simultaneously turns the bearing crank to bring the pip right or left to the director bearing line.

Figure 26E15 shows the appearance of all three radar scopes for different positions of the target. The equipment is tracking target *C*; therefore the pip from target *C* is against the range mark on the A-sweep, at the step on the R-sweep, at the center of the trace in the E-scope, and at the center of the B-scope. All targets covered by the spiral scan appear on the A-sweep and E-scope. Target *E* does not appear on any scope, because it is too far from the antenna axis. Target *A* does not appear on the B-scope, because it is more than 1,000 yards from the range mark. Targets

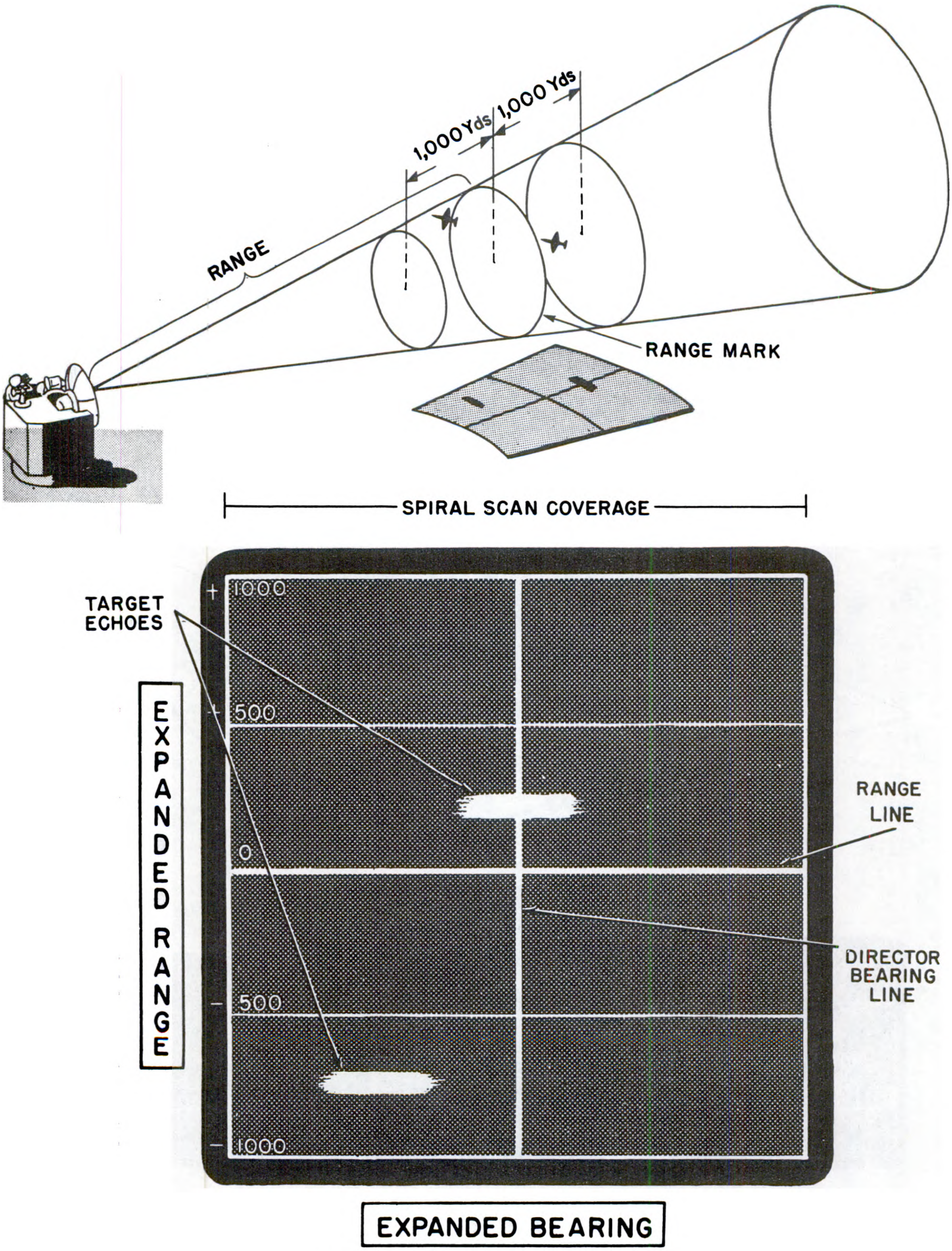
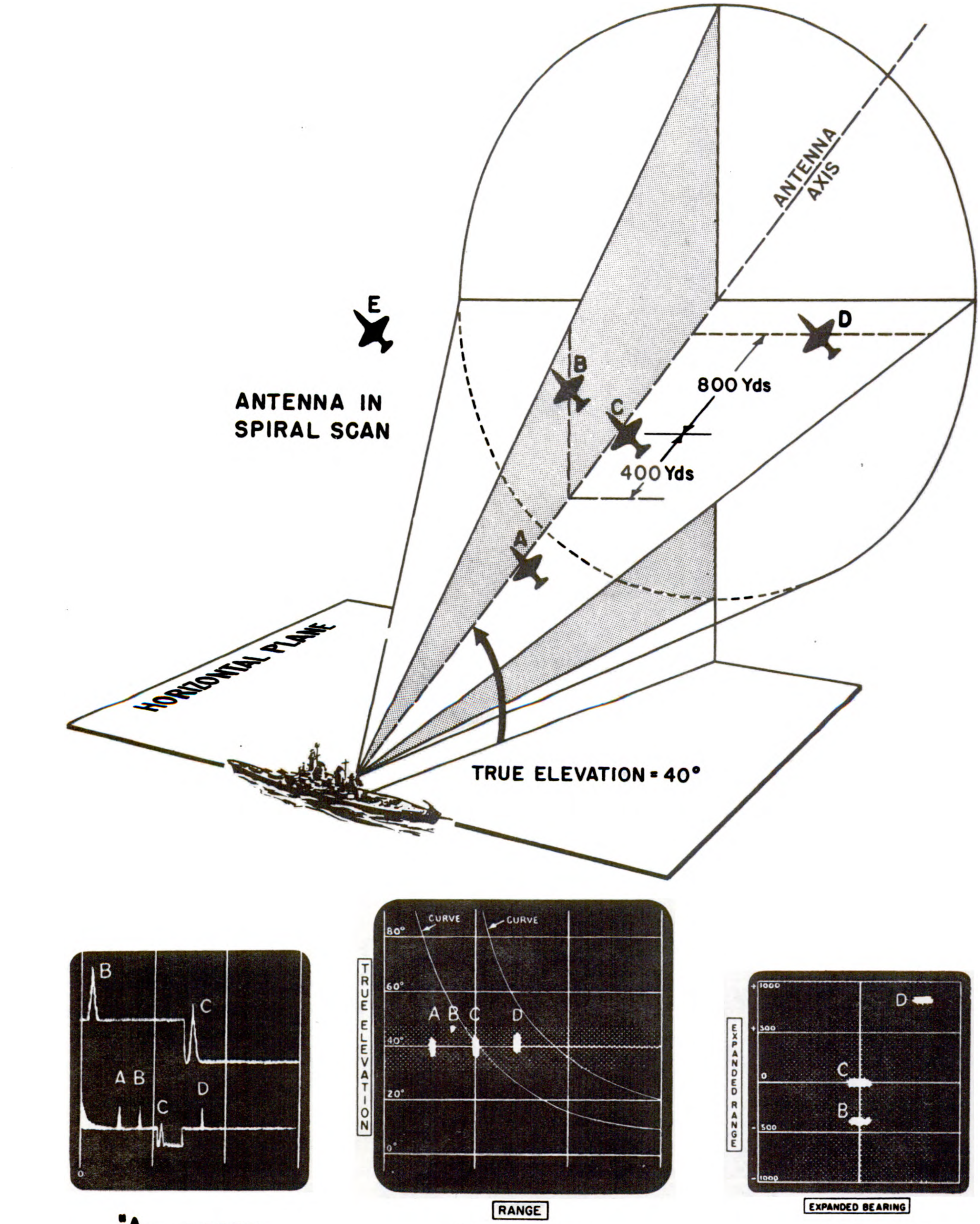


FIGURE 26E14.—B-scope presentation.



"A/R" SCOPE "E" SCOPE "B" SCOPE

FIGURE 26E15.—Interpretation of radar scopes.

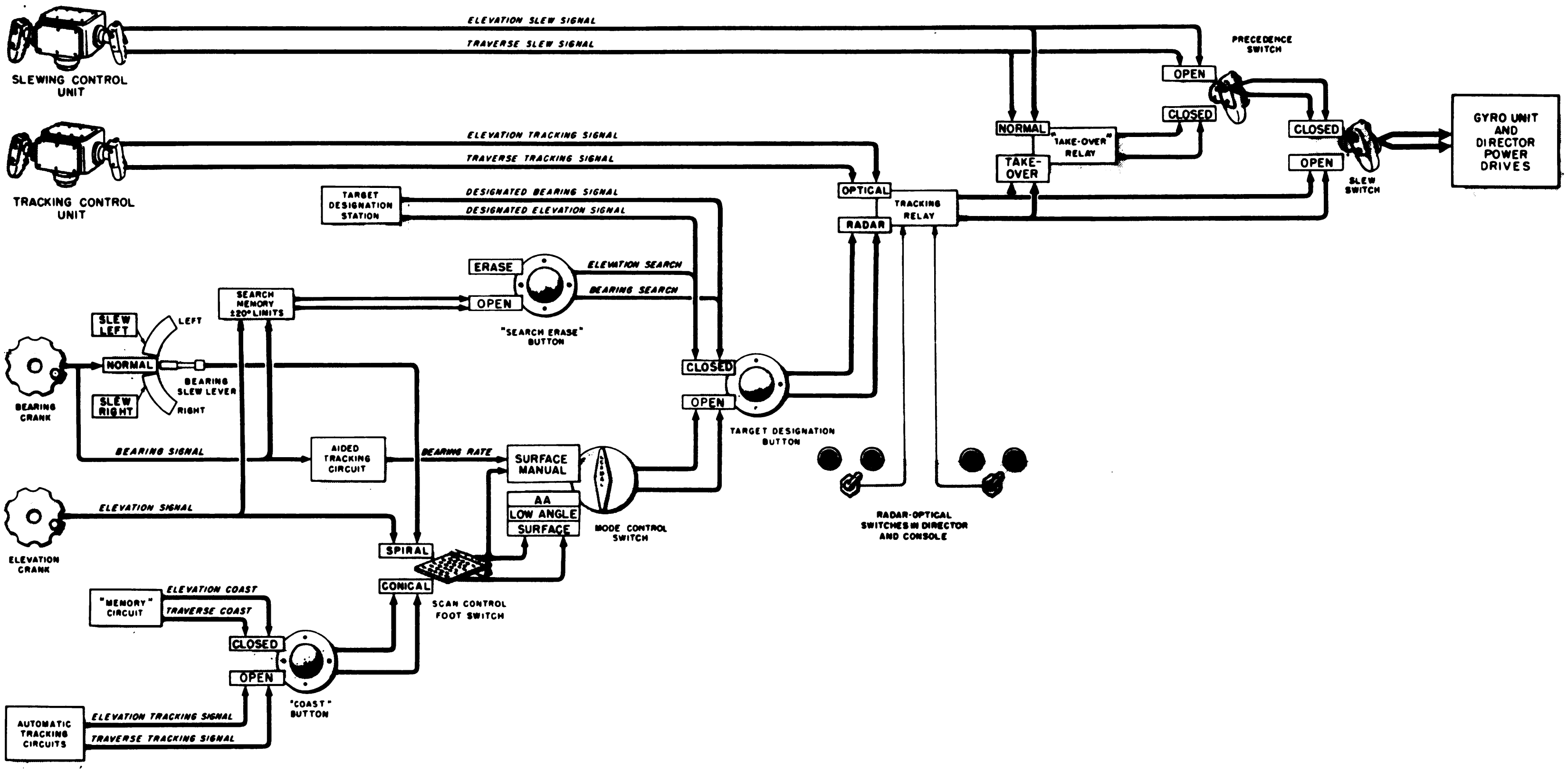


Figure 26E16.—Complete tracking control switching.

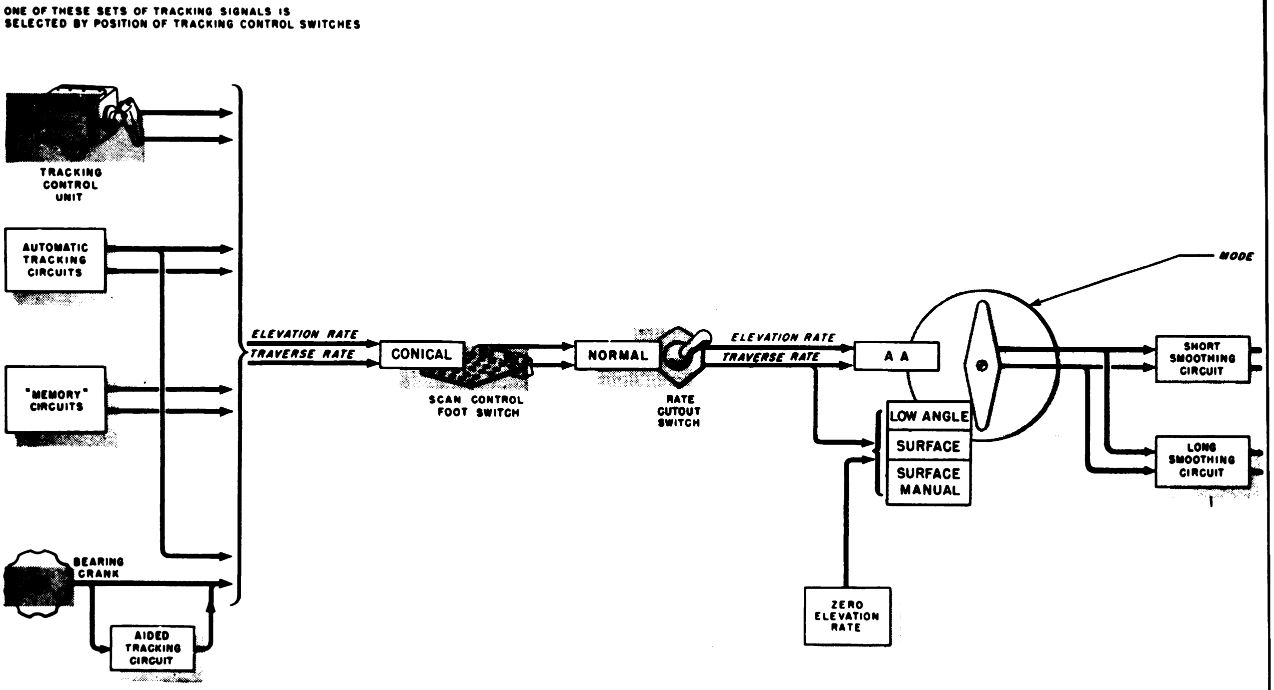


FIGURE 26E17.—Complete computer mode switching.

A and *D* do not appear on the R-sweep, because they are more than 500 yards away from the range mark.

3. The *range crank* positions the range mark on the target pip. One revolution of the knob changes the radar range by 2,000 yards. The range knob generates aided tracking signals when the range control switch is at AIDED AA or AIDED SURFACE.

4. The *mode control switch* controls both tracking and computing modes of operation. This switch has four positions: AA, LOW ANGLE, SURFACE, and SURFACE MANUAL.

On AA, the usual setting, automatic tracking and normal computing are allowed.

LOW ANGLE position is used when the low angle buzzer sounds, indicating a target below 1 degree elevation. In this setting, automatic tracking is permitted, except that the elevation tracking rate is zeroed, inasmuch as this signal is erratic for targets at this low angle.

The SURFACE setting is used for automatic tracking of surface targets. In this setting also, the elevation rate is zeroed; however long smoothing is introduced into the computation of lead angles. *Long smoothing* means that a greater solution time is used in order to give more stable gun orders for surface firing.

The SURFACE MANUAL setting is used for large surface targets with low rates of motion. It allows automatic tracking at zero elevation and range only. Tracking in bearing must be performed manually. The effect of this mode on computation is that elevation rates are zeroed and long smoothing is introduced.

5. The *bearing slew lever* slews the director in train.

6. The *bearing crank* positions the director in train. It is used for more sensitive control of director train than is provided by operating the slew lever.

7. The *rate cutout switch* cuts out the traverse and elevation rate inputs to the computer during training periods, to save wear on the computer. The lamp is lit only when the rates are cut out.

8. The *target designation button* automatically synchronizes the system with designated values of bearing, elevation, and range. The indicating lamp lights when a designating station is transmitting a target designation.

9. The *scan control pedal* controls antenna scan when the scan control switch is on FOOT SWITCH. The radar tracker selects SPIRAL when searching and CONICAL when tracking. To change from one to the other, he presses the pedal, which is a sequence-type "press-to-change" switch. The only visible indication of whether the pedal is on SPIRAL or CONICAL is the width of the trace on the radar indicators.

Operation of the automatic tracking circuits is interlocked with the type of antenna scan. Automatic tracking in bearing, elevation, and range is possible only in conical scan. Also, automatic gain control normally depends upon conical scan.

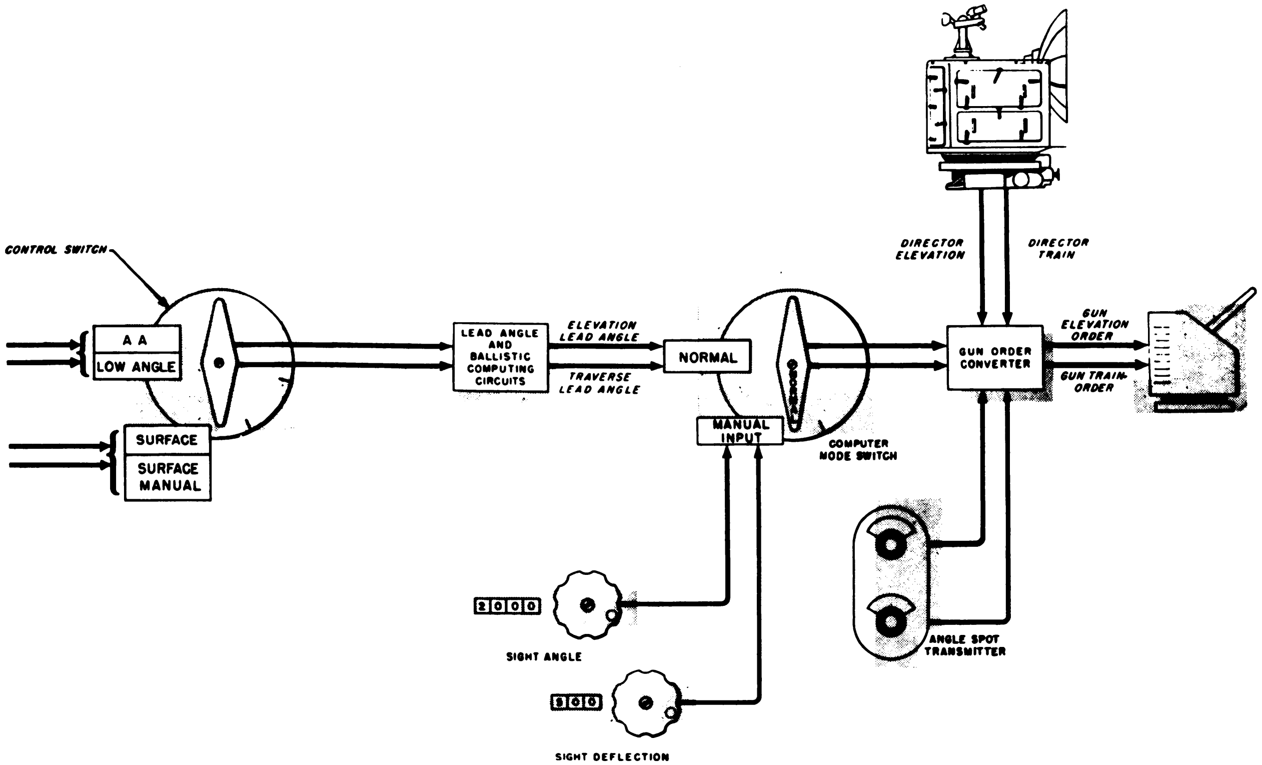


FIGURE 26E17.—Continued.

In spiral scan, only manual tracking is possible; however, the bearing crank is operative in conical scan when the mode control switch is set at SURFACE MANUAL.

10. The *search erase* button erases the signal superimposed manually by the console operators when the system is synchronized with designation data. After pressing the target designation button, the operators can search ±20 degrees from the designated elevation and bearing and ±4,000 yards from the designated range. If the target is not acquired then, the search erase button is pressed and the system resynchronizes with the designated values.

11. *Director bearing dials.* The radar tracker receives indications of director bearing from three dials. The true-bearing dial on the E-indicator panel shows the bearing of the director from true North. The director-train dial on the console right-hand dial panel shows relative director bearing (relative to bow of own ship), and designated relative target bearing. Bearing Indicator Mark 10, attached to the right side of the console, shows both true and relative director bearing on the same dial face.

When bearing is designated, the tracker may slew the director to match the zero of the director-train dial with the designated bearing pointer. Normally, this is done automatically by pressing the target-designation push button.

When bearing is designated by telephone only, automatic synchronization is not possible and the designated-bearing dial is disregarded.

12. Ship speed is normally introduced automatically, but can be set in manually by matching pointers on the inner and outer ship-speed dials.

13. *Wind-speed* and *wind-direction knobs* and *dials.* The radar tracker sets true wind speed and true bearing of true wind into the computer manually, in accordance with the values received by telephone.

14. *Dead-time knob and dial.* The radar tracker sets dead time into the computer manually by turning this knob. The dial is graduated in seconds from 2 to 6.

15. *Fuze-spot knob and dial.* By means of this knob, the radar tracker manually introduces range-spot corrections, from the control officer or the radar operator.

16. The angle spot transmitter has an elevation spot dial and a deflection spot dial, each graduated in mils. Spots may be introduced by the radar tracker and estimated by the console operators or the control officer.

26E14. Summary of operational controls—tracking control switching

Figure 26E16 shows the functional arrangement of all controlling units and switches affecting tracking control.

All signals for positioning the director are introduced into the gyro unit, where they are combined with the stabilizing signals and then transmitted to the director drives.

The slew switch takes precedence over all other switches. When closed, it allows only signals from the slewing sight to be introduced to the gyro unit, except when the precedence switch is also closed; then either the tracking control unit or the console can override the slew signals, if the appropriate take-over switch is closed. The position of the radar-optical switch determines which of these two stations can take control.

Next in importance after the slew switch is the radar-optical switch. When on OPTICAL, it selects only the signals from the tracking control unit; when on RADAR, it allows signals from the console to take over.

The target-designation push button takes precedence over all other console controls. When closed, it selects the designating signals from the target designating station. Signals from the bearing and elevation cranks on the console may be introduced to search within ±20 degrees of designated values.

When the mode control switch is set at SURFACE MANUAL, the bearing crank on the console has control of director bearing. Either manual or automatic tracking in elevation is possible, depending on the type of scan control in use. The other three positions of the mode control switch allow full automatic tracking, depending on scan control.

The scan control foot switch serves the function of choosing between manual and automatic tracking. With the scan control in SPIRAL, only manual tracking (with the bearing crank, slew lever, and elevation crank) is possible. The bearing crank signal goes through only if the bearing slew lever is set at NORMAL.

Automatic tracking is possible only in conical scan. The memory circuits are substituted for the automatic tracking circuits when the coast push button is pressed. The automatic tracking circuits will control the director if: (1) the coast push button is on OPEN; (2) the scan control pedal is on CONICAL; (3) the mode control switch is set at AA, SURFACE, or LOW ANGLE; (4) the target-designation push button is on OPEN; (5) the tracking switch is in RADAR; and (6) the slew switch is OPEN, or, if closed, when the precedence switch is also closed so as to activate the TAKE-OVER mode of the take-over relay. The scan control foot switch serves as the take-over switch for radar tracking, actuating the TAKE-OVER mode in conical scan.

Computer mode switching. Figure 26E17 shows the controls affecting computer operation. The elevation and traverse rates introduced into the computer for computing lead angles are the same as those transmitted to the gyro unit for positioning the director. However, the computer does not receive slewing rates nor, generally, rates from the console cranks.

The only traverse and elevation rates received by the computer are those from: (1) the tracking control unit, (2) automatic tracking circuits, (3) memory circuits, and (4) the bearing crank when the mode control switch is set at SURFACE MANUAL. The mode control switch serves a dual function. First, it substitutes zero elevation rate when in positions: LOW ANGLE, SURFACE, or SURFACE MANUAL. Second, it selects short smoothing or long smoothing, depending on whether the target is a plane or a ship.

In order to introduce any one set of these rates into the computer, the computer mode switch must be on NORMAL. Lead angles are computed from these rates, ballistic corrections added, and the total lead angles transmitted to the gun order converter, where they are combined with director train and elevation. The resultant gun orders are then transmitted to the gun.

When the computer mode switch is on MANUAL INPUT, all rate inputs are cut out and the computer calculates no ballistic corrections. Instead, the manually introduced values of sight angle and sight deflection are introduced into the gun order converter in place of the total lead angles. Sight angle and sight deflection are combined with director train and elevation to produce gun orders.

Chapter 27

TORPEDO FIRE CONTROL

A. General

27A1. Introduction

The torpedo is recognized as the most effective underwater weapon of naval warfare. It may be fired from submarines, aircraft, or surface vessels. The enormous damage inflicted by torpedoes on our own and enemy forces in the last war is well known. Not so apparent, but still of considerable importance in its effect on tactics, is the constant threat of torpedo attack, present whenever enemy light forces, aircraft, or submarines are known or suspected to be in the vicinity.

The torpedo fire control problem is quite different for destroyers, submarines, and aircraft. In this chapter we will consider only the control of torpedoes fired from a destroyer. The prospective naval aviator or submariner will receive extensive special training in the problem of torpedo fire control from his type of craft.

The primary consideration in a torpedo attack is doctrine, for, if the attack is to be coordinated, all ships participating must act in accordance with the same principles. The successful execution of the mission is dependent upon how thoroughly the various ships adhere to doctrine. Since torpedo attacks may be made under all conditions of visibility, provision must be made for establishing the LOS both optically and by radar. Commanding officers, CIC evaluators, torpedo fire control officers, and all torpedo personnel must be thoroughly cognizant of such phases of the doctrine as may apply to them and their stations.

A destroyer torpedo attack will usually be detected by the target ship in the early stages; therefore the torpedoes must be fired at comparatively long ranges. Unfortunately, this gives the target time to maneuver so as to avoid being hit. For this reason, destroyers usually fire several torpedoes in rapid succession in a spread pattern (see art. 27B3). This procedure greatly increases the possibility of obtaining a hit. A division of destroyers in battle usually fires its torpedoes as a unit, with each ship firing a spread. This combination of spreads produces a pattern which is almost certain to give some hits. With spread firing it is possible to neglect certain minor errors which would have to be considered if a single torpedo were fired to hit a given point of aim.

B. Destroyer Torpedo Fire Control Problem

27B1. The torpedo speed triangle

Before proceeding with a study of the fire control instruments and methods of controlling torpedo fire, certain basic elements in the problem must be understood. Figure 27B1 is the basic speed or vector triangle of torpedo fire. It is a graphic representation of the intercept problem in which the torpedo is directed along the correct course to hit the target. Definitions associated with this triangle are as follows:

1. *Firing point.* The point where the torpedo begins its run; broadly the position of the firing ship when the torpedo is launched.

2. *Point of aim.* The desired point on the target to be hit with the torpedo.

3. *Point of intercept.* The point where the torpedo hits the target or crosses the target's track (or target's track extended).

4. *Line of sight.* The straight line from the axis of rotation of the torpedo director to the point of aim on the target.

5. *Target speed, St.* Speed of the target in knots.

6. *Torpedo speed, Sa.* The average speed in knots of the actual torpedo from the tube muzzle to the point of intercept.

7. *Target angle, A.* The relative bearing of the firing ship from the target. Target angle is measured clockwise from the target's bow to the line of sight between target and firing ship. ($A=B+180^\circ-Ct.$)

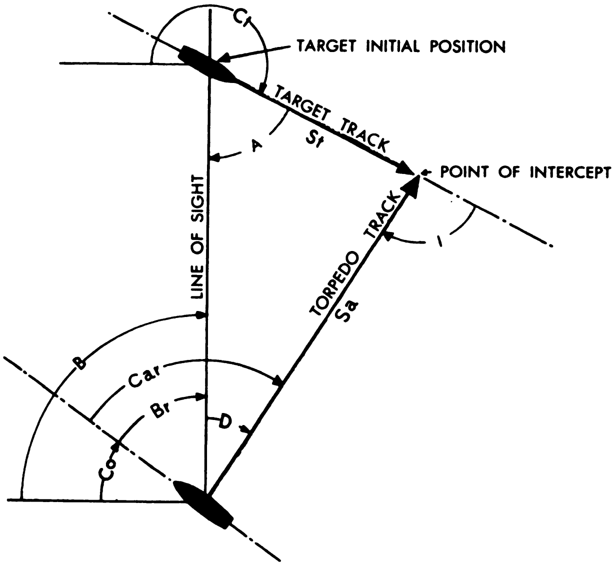


FIGURE 27B1.—Torpedo speed triangle.

8. *Track angle, I.* The angle at the point of intercept between the target's course and the reverse course of the torpedo, measured clockwise from the target's course. The ideal track angle is usually considered to be 90° or 270°, because under such conditions the target ship is squarely broadside, thus offering the largest target area.

9. *Basic sight angle, D.* The computed angle from the line of sight to the final track of the torpedo, measured clockwise. It must be emphasized that *D* is independent of range; it is, however, dependent on torpedo speed, which must be decreased if ranges are excessively long.

The sight-angle solution is affected by the following factors:

a. Line of sight—determined visually or by radar.
b. Target angle or target course—estimated or found by tracking.
c. Target speed—determined by eye estimate, or by tracking.
d. Torpedo speed—known in advance from the speed setting ordered.

27B2. The torpedo distance triangle

The speed and distance triangles of torpedo fire are similar and may be superimposed. However, it is important for the student to recognize that these two triangles are constructed with different scales, and therefore must be used independently in the two parts of the problem. The distance triangle is shown in figure 27B2. Definitions associated with the distance triangle are as follows:

1. *Torpedo track.* The line along which the torpedo travels through the water after it has steadied on its set course.

2. *Target track.* The line along which the target is moving.

3. *Torpedo range.* The distance in yards which a torpedo is designed to travel before its speed falls off.

4. *Torpedo run.* The distance in yards which the torpedo travels from the firing point to the point at which it crosses the target's track (or target's track extended).

5. *Target run.* The distance run by the target during the time of torpedo run.

6. *Overrun.* The distance in yards which a torpedo will run at its designed speed after crossing the target's track (or track extended). Torpedo range equals torpedo run plus overrun.

7. *Firing range.* The distance in yards between the firing ship and the target at the instant of firing.

8. *Maximum range.* The greatest firing range at which a torpedo may be fired and have sufficient endurance to intercept the target at its designed speed. It is the firing range which will result in a torpedo run equal to 100 percent of the torpedo range. It varies

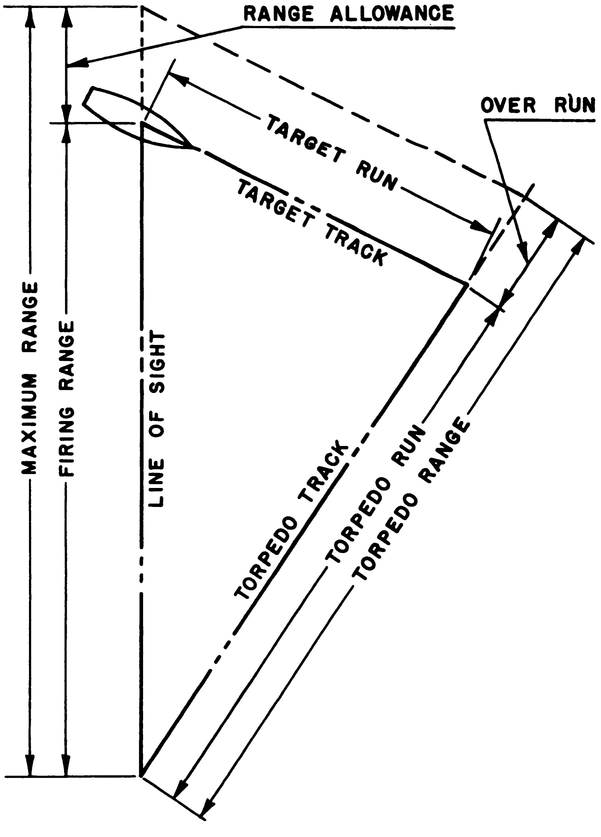


FIGURE 27B2.—Torpedo distance triangle.

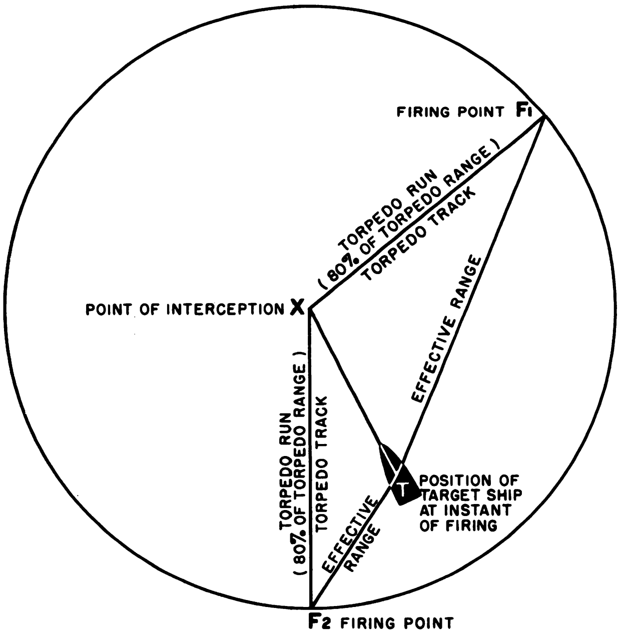

FIRING POINT F1
TORPEDO RUN (80% OF TORPEDO RANGE)
TORPEDO TRACK
EFFECTIVE RANGE
POINT OF INTERCEPTION X
TORPEDO RUN (80% OF TORPEDO RANGE)
TORPEDO TRACK
T
POSITION OF TARGET SHIP AT INSTANT OF FIRING
EFFECTIVE RANGE
F2 FIRING POINT

FIGURE 27B3.—Change in effective range for different firing positions.

with different firing situations, as does effective range, below.

9. *Range allowance.* The margin of firing range allowed to ensure that the torpedo run will be less than the torpedo range. Maximum range equals firing range plus range allowance.

10. *Effective range.* The greatest firing range permitted by doctrine. It is a firing range such that the resultant torpedo run will equal a specified (high) percentage of the torpedo range. (The specified percentage may be so chosen as to leave a small amount of overrun.) Effective range is the range to which the firing ship must close the target before firing torpedoes. It varies with different firing situations, being dependent upon:

a. Torpedo speed setting.
b. Target speed.
c. Target angle.

Figure 27B3 illustrates the effective range circle of torpedo fire. The line TX represents the distance and direction the target will travel while the torpedo travels a specified percentage (as in 10 above) of its designed range. The circle represents the locus of all firing positions for an effective range shot for the particular target speed and torpedo speed on which the diagram is based.

It can be seen that firing positions on the target's bow, such as F_1, give an effective range greater than the specified percentage of torpedo range, and firing positions such as F_2, on the quarter, give an effective range less than the specified percentage of torpedo range.

27B3. Methods of firing

The two methods of firing torpedoes are: (1) straight fire, and (2) curved fire. In both methods, the torpedoes are normally fired in a *spread,* produced by setting small angular offsets onto the torpedo gyro mechanism of the individual torpedoes. Curved fire is accomplished by setting an additional uniform offset angle on all the torpedoes in the mount to the angle it is desired for the torpedoes to turn right or left after being launched. Torpedo-tube mounts have limited sectors in which torpedoes can be launched without striking some part of the firing ship's structure. It is therefore frequently necessary to use curved fire to *unmask* the torpedo battery if the tactical situation does not permit changing course. The two methods of firing torpedoes are shown in figure 27B4, along with further elements of the torpedo control problem. Definitions associated with these figures are as follows:

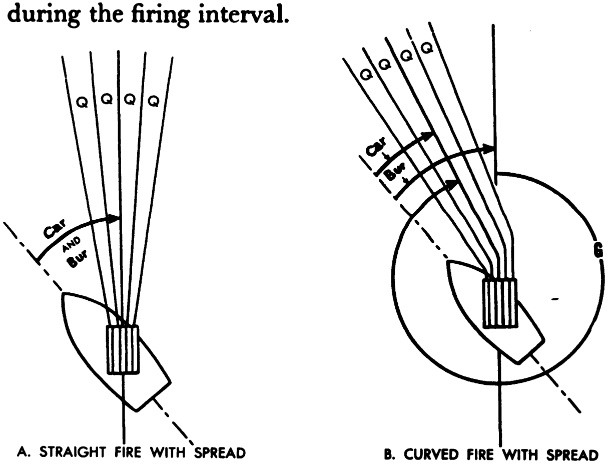
1. *Basic tube train, Bur.* The computed angle between the fore-and-aft axis of the firing ship and the axis of the torpedo-tube mount, measured clockwise from the firing ship's bow.

2. *True torpedo course, Ca.* The angle between the north-south line and the final mean track of the actual torpedoes, measured clockwise from north.

3. *Relative torpedo course, Car.* The angle between the fore-and-aft axis of the firing ship and the final mean track of the actual torpedoes, measured clockwise from the firing ship's bow.

4. *Gyro angle, G.* The angle betwen the axis of the torpedo-tube mount and the final mean track of the torpedoes, measured clockwise from the axis of the tube mount.

5. *Spread angle, Q.* The angular difference between the final track of two adjacent torpedoes fired from the same tube mount, after algebraic addition of any angular change caused by relative target motion during the firing interval.



A. STRAIGHT FIRE WITH SPREAD

B. CURVED FIRE WITH SPREAD

FIGURE 27B4.—Methods of torpedo fire with movable tube mounts.

C. Destroyer Torpedo Fire Control System

27C1 Torpedo fire control

Torpedo fire control is a subdivision of fire control and comprises the system of directing the launching of a ship's torpedoes. It includes material, personnel, communications, and organization. It deals with the launching of a relatively slow missile through the water on the correct course to intercept a target. The functions of torpedo fire control are as follows:

1. Determination or estimation of target motion.
2. Selection of torpedo settings for speed and depth.
3. Determination of sight angle.
4. Determination of spread plan and offsets.
5. Aiming.
6. Tube laying.
7. Firing.

27C2. The control of firing

The two kinds of control used for torpedo fire are: (1) bridge control, and (2) local control. Bridge control is remote control from directors. This is the primary method of control on modern destroyers. The torpedo fire control problem is solved at the torpedo director, in conjunction with information from CIC. Relative torpedo course and basic gyro-angle orders are transmitted electrically from the director to indicators at the tube mount, and the mount is properly trained by matching dials. Local control is accomplished at the tube mount, and is normally used when the director control system is inoperative. In this method, the torpedo fire control problem is usually solved by means of the torpedo-tube mount sight. The sight is offset properly, and then the tube is trained until the sight is on the point of aim. Spreads may be fired by setting spread angles on the torpedo gyros or by varying the point of aim. In either case the director continues to solve the problem during the intervals between the firing of the several torpedoes, thus creating a small additional variation between the tracks of the several torpedoes.

27C3. The Torpedo Director Mark 27

Most destroyers are fitted with two Torpedo Directors Mark 27 mounted on the wings of the signal bridge, one on each side; and either of these directors may control the fire of the single centerline quintuple-tube mount usually installed. As mentioned in chapter 21, proper alignment of the torpedo fire control system is a prerequisite to an accurate solution of the problem. The primary function of the torpedo director is to control one or more tube mounts by electrically indicating to them the torpedo course for hitting the target at which the director is aimed. To do this, the director performs the following functions:

1. Measures relative target bearing (*Br*) automatically if the director trainer keeps the line of sight on the target or matches pointers in accordance with radar information.

2. Computes basic sight angle (*D*) from the initial inputs of torpedo speed, target speed, and target angle. (Note that range is not an input to the director.)

3. Combines relative target bearing with basic sight angle to produce relative torpedo course *Car* for transmission to the tube mounts. The design of the director makes it possible for spread angles, latitude correction, and aiming corrections to be applied to *Car* prior to transmission to the mounts, as will be described later.

The principal parts of the Mark 27 director are: (1) the stand, (2) the case, (3) the telescope unit. The *stand* is bolted to the deck and supports the case on ball bearings. A training circle secured to the stand meshes with a gear driven by the training handwheel mounted on the case. Rotation of the training handwheel turns the case with respect to the stand; rotation is limited to about 390 degrees.

The *case* houses the units which solve the torpedo fire control problem, transmit torpedo course (*Car*) and gyro angle (*G*) to the tube mounts, and receive own ship's course (*Co*) from the gyro compass. The knobs for hand inputs and all dials are attached to the case. All inputs are manual except own ship's course (*Co*), and if the automatic transmission fails, the *Co* knob can be used to introduce this value manually.

The *telescope unit* is normally positioned by a servo follow-up motor within the case. This may also be done manually with the sight-angle crank, on the right side of the case. The Telescope Mark 50 consists of a tiltable mirror and fixed-prism telescope mounted on a pivot. The tiltable mirror makes it possible to hold the line of sight on the target as the ship rolls and pitches. The pivot is supported on a ball-bearing assembly attached to the top of the case. It is geared to the computing mechanism within the case and is automatically turned with respect to the case through the computed sight angle.

27C4. The director solution

In solving the torpedo problem by a director the initial set-up is made by (1) making manual settings of *St, Sa, Ct* or *A,* (and of *Co* if not received electrically) (2) receiving own ship's course *Co* electrically, and (3) keeping the telescope line of sight on the

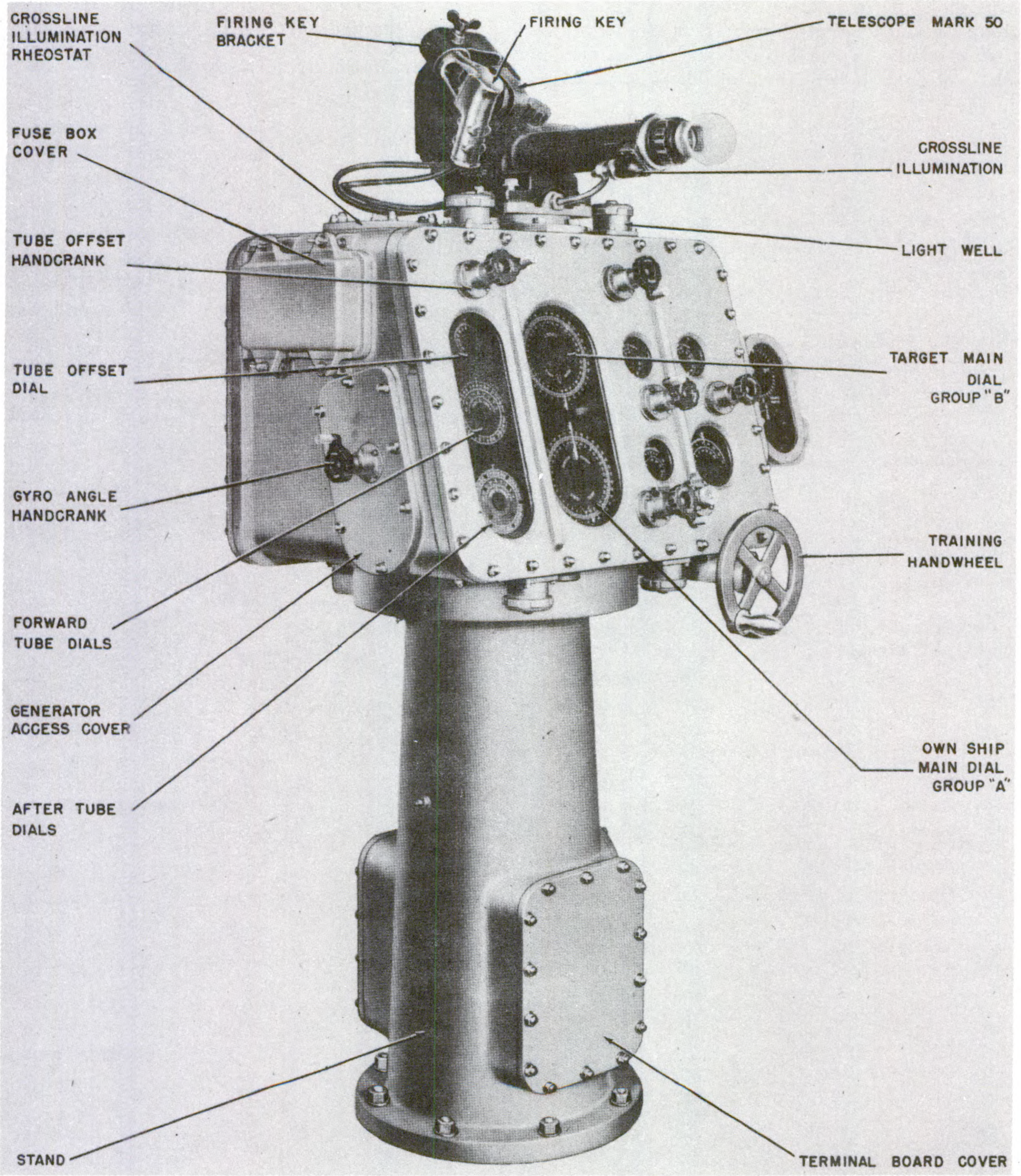


Figure 27C1.—Front left view, Torpedo Director Mark 27.

target. The introduction of these settings will set up on the main dial group of the director a picture such as shown in figure 27C3. In each dial group the outer ring is a compass ring, the middle ring represents the ship (own ship in group A, target ship in group B), and the central ring represents the torpedo track in relation to own ship and target. The director solves for sight angle by the principle of *equal deflections* in which torpedo deflection (Xa) must equal target deflection (Xt). Then since $Xt=St \sin A$ and $Xa=Sa \sin D$, $\sin D$ equals $\frac{St \sin A}{Sa}$. Figure

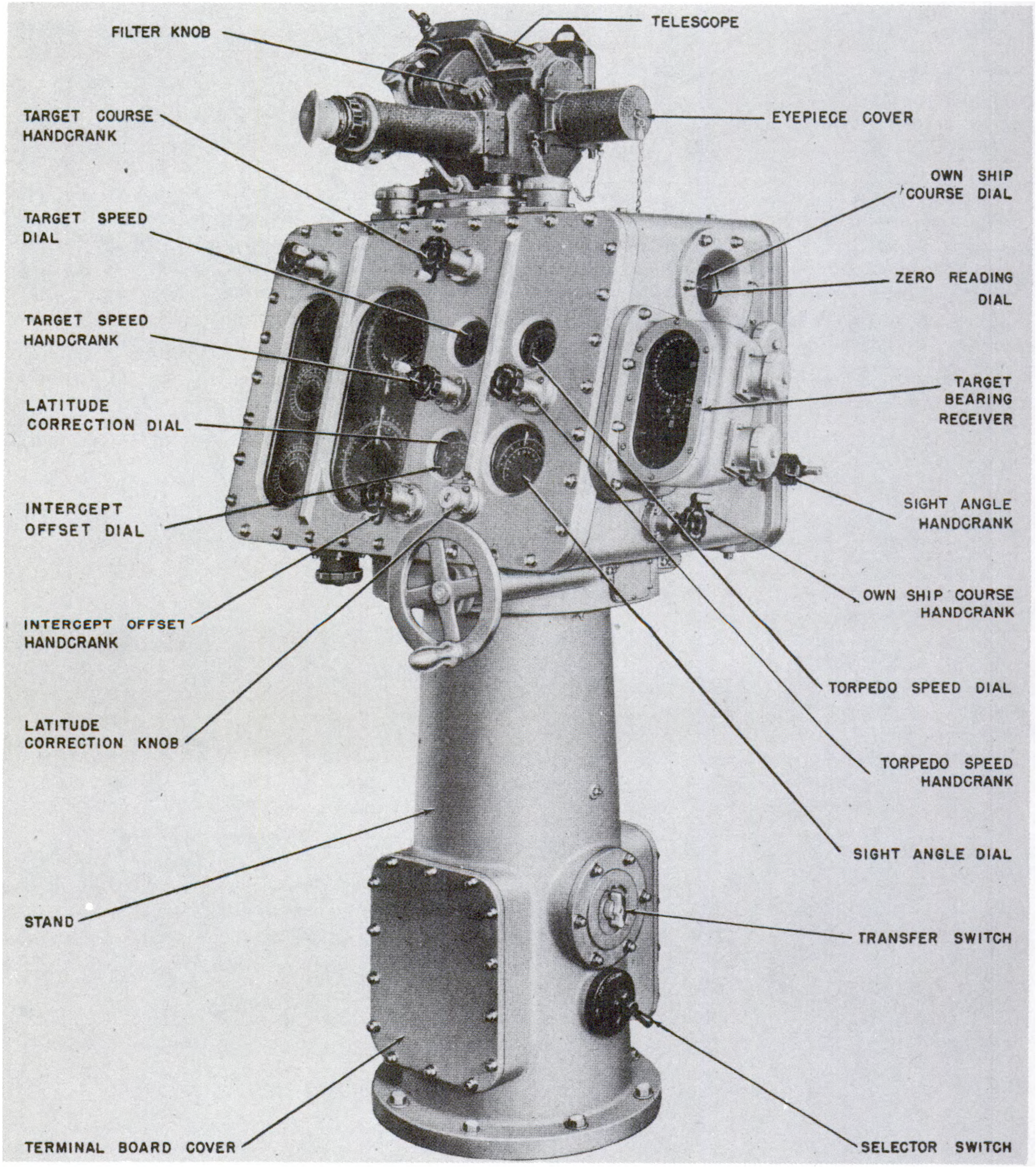


FIGURE 27C2.—Front right view, Torpedo Director Mark 27.

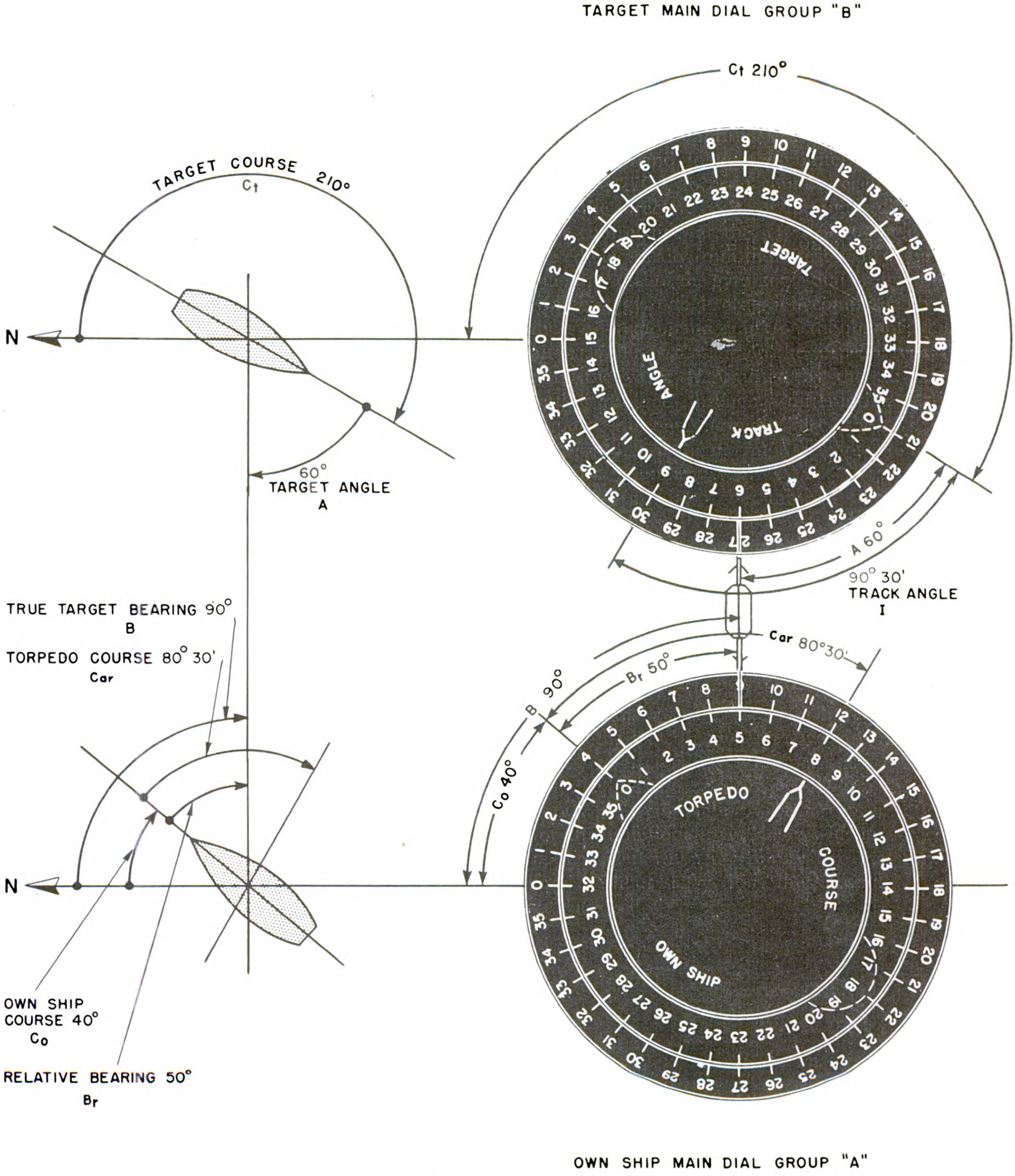


FIGURE 27C3.—Main dial group of torpedo director.

27C4 (A) shows the elements of the firing-ship-target set-up and figure 27C4 (B) shows how two component solvers are used to solve for *D*. In this elementary solution, gyro angle, latitude correction, intercept and tube offsets, and spread angles are not considered. The target solver, from inputs of target course, target speed,

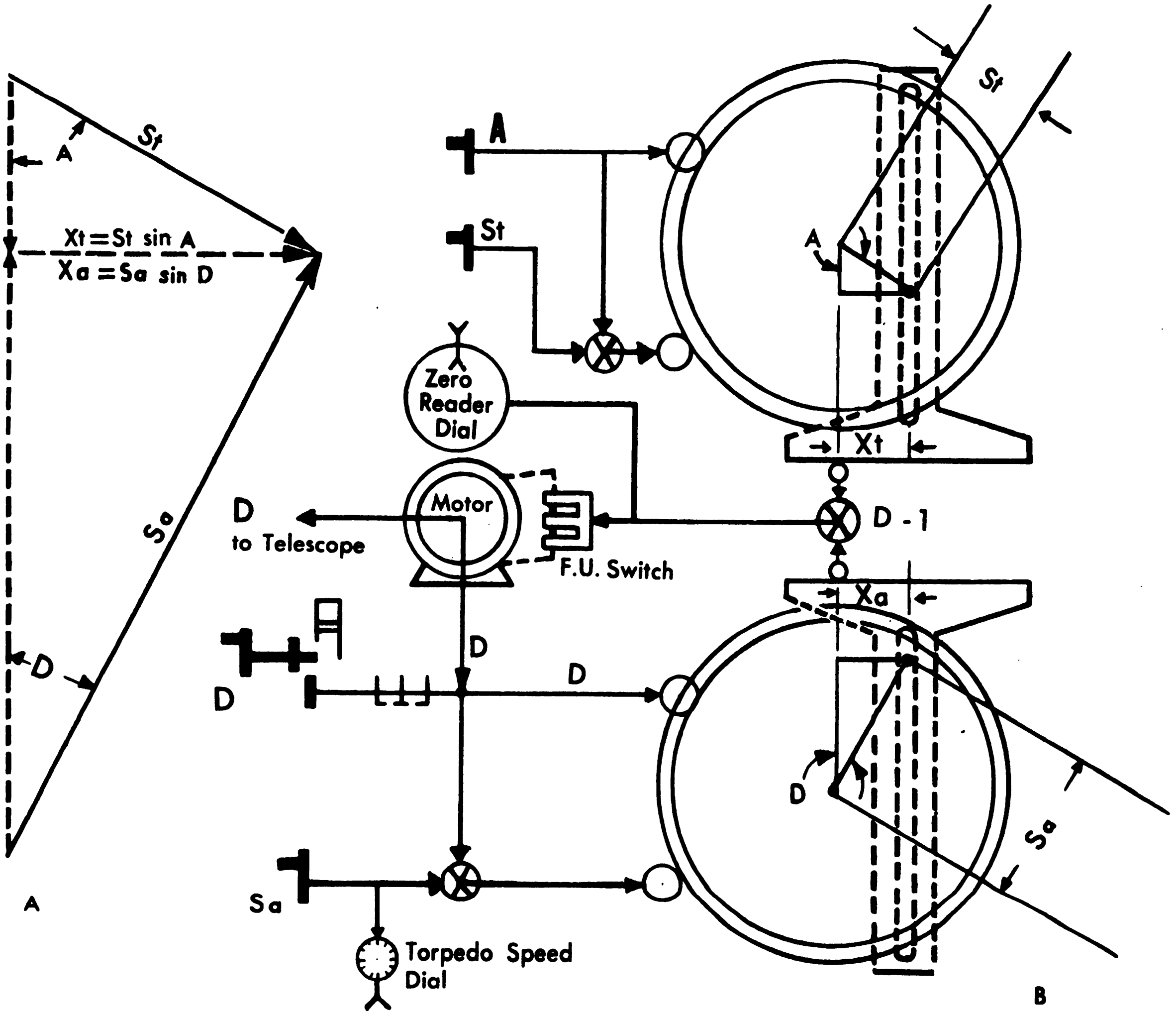


FIGURE 27C4.—Director solution of torpedo triangle.

own-ship course, and relative target bearing, produces *Xt* (target deflection component). The sight-angle solver, with an input of torpedo speed, is rotated through an angle of *D* (sight angle) by the sight-angle servo motor or the sight-angle hand crank, until its output, *Xa* (torpedo deflection) equals *Xt*. When *Xt* equals *Xa*, the zero-reader dials in the torpedo director are matched.

At this point the following relationships exist:

Since the telescope LOS is directed at the target, the angle measured clockwise from the ship's bow to the telescope axis is relative target bearing *Br*.

2. The telescope unit has been offset from the line perpendicular to the face of the director case by the amount of basic sight angle *D*.

3. The angle between the bow of the firing ship and a line perpendicular to the face of the case is *Br* plus *D*, which (if corrections be disregarded) equals *Car*. Thus the perpendicular to the face of the director case is parallel to the mean track of the torpedoes.

27C5. Corrections to basic sight angle

Corrected sight angle is obtained by modifying *D* for latitude correction, *Gm*, and intercept offset, *Osi*.

Latitude correction, set manually, compensates for the inherent tendency of the torpedo gyro to creep to the right in north and to the left in south latitudes, due to the rotation of the earth. (No correction is necessary unless the latitude in which the torpedoes are to be fired differs from that at which they were last proved or at which their gyros were last balanced.) The magnitude of the correction depends upon the length of the torpedo run and the latitude. The

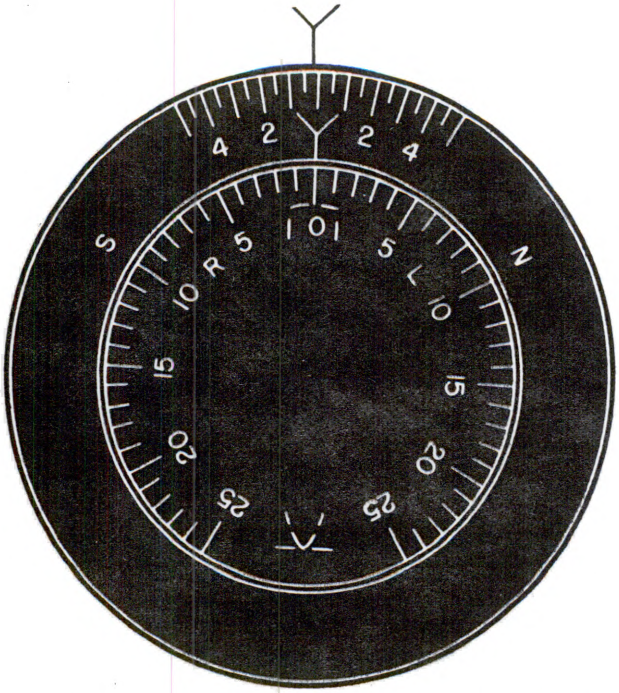


FIGURE 27C5.—Latitude correction and intercept offset dial (10′ south latitude set).

amount of correction necessary is determined from a "click table" which indicates the number of clicks of the latitude-correction knob required to correct for the latitude in question. Each click moves the dial 10 minutes.

Figure 27C5 shows the latitude correction and intercept offset dial. The outer ring is used for latitude settings and the inner dial for setting intercept offset, as will be explained below. In the figure, 10′ south latitude correction has been set by rotating the outer ring, causing the *S* portion to lie opposite the fixed index. The intercept offset dial does not move while making this setting and must be rotated until the zero mark is opposite the index on the latitude ring. This rotation of the intercept offset dial introduces the latitude correction into the director.

Intercept offset, set in manually, is primarily used to correct for the turning circle of the torpedo when fired with large gyro angle. After launching, the torpedo turns right or left through the set gyro angle to its running (final) course. The gyro angle, it will be remembered, equals the angle between the tube axis at the instant of firing and the final torpedo course. When firing angled shots, an aiming correction must be applied to compensate for the turning circle effect. The amount of this correction depends upon the following:

1. Amount of gyro angle.
2. Direction of gyro angle.
3. Speed setting of the torpedo.
4. Run of the torpedo to intercept point.
5. The mark of the torpedo.

Tables are provided showing the amount of this correction for various combinations of the above variables. The correction taken from the table is to be applied by turning the intercept offset knob in the same direction as the applied gyro angle, through the amount of the correction. This will turn the inner dial, figure 27C5, right or left in accordance with the markings R and L.

The setting of intercept offset is not made until the latitude setting has been completed with the intercept offset dial zeroed on the fixed index of the latitude ring. If this procedure were not followed, erroneous inputs would result.

Another use of the intercept offset dial is to provide a small variation in sight angle to compensate for expected target maneuvers in attempting to avoid the torpedoes. In the case shown in various figures in this chapter, the target may be expected to turn toward the oncoming torpedoes, in an attempt to parallel the torpedo tracks. The intercept offset knob could be used to decrease by a small amount the computed value of sight angle, in order to nullify the effect of this maneuver.

Basic sight angle as corrected by *Gm* and *Osi* constitutes *corrected sight angle, D′.* This quantity, added to *Br,* produces *Car,* which is the primary output to the torpedo course indicator at the tube mount.

27C6. Determination of basic tube train

Torpedo course, *Car,* as explained in article 27B3 consists of the sum of basic tube train, *Bur,* and gyro angle, *G.* Control personnel on the bridge may select values of *Bur* and *G* which, combined, will give the proper value of *Car,* because gyro angle may be set manually by means of a crank in the left side of the director case. In making the settings the dials shown in figure 27C6 are used. On the forward tube dial group, gyro angle is set on the center ring dial opposite the fixed gyro-angle index (the reading shown being 330 degrees). The diagram shows how torpedoes from both mounts turn left 30° to their final course. A setting of 360° indicates zero gyro-angle set; a setting 030° would indicate a right gyro angle.

The set value of gyro angle is transmitted directly to the torpedo course indicator at the tube mount, where it is indicated and used as will be explained later.

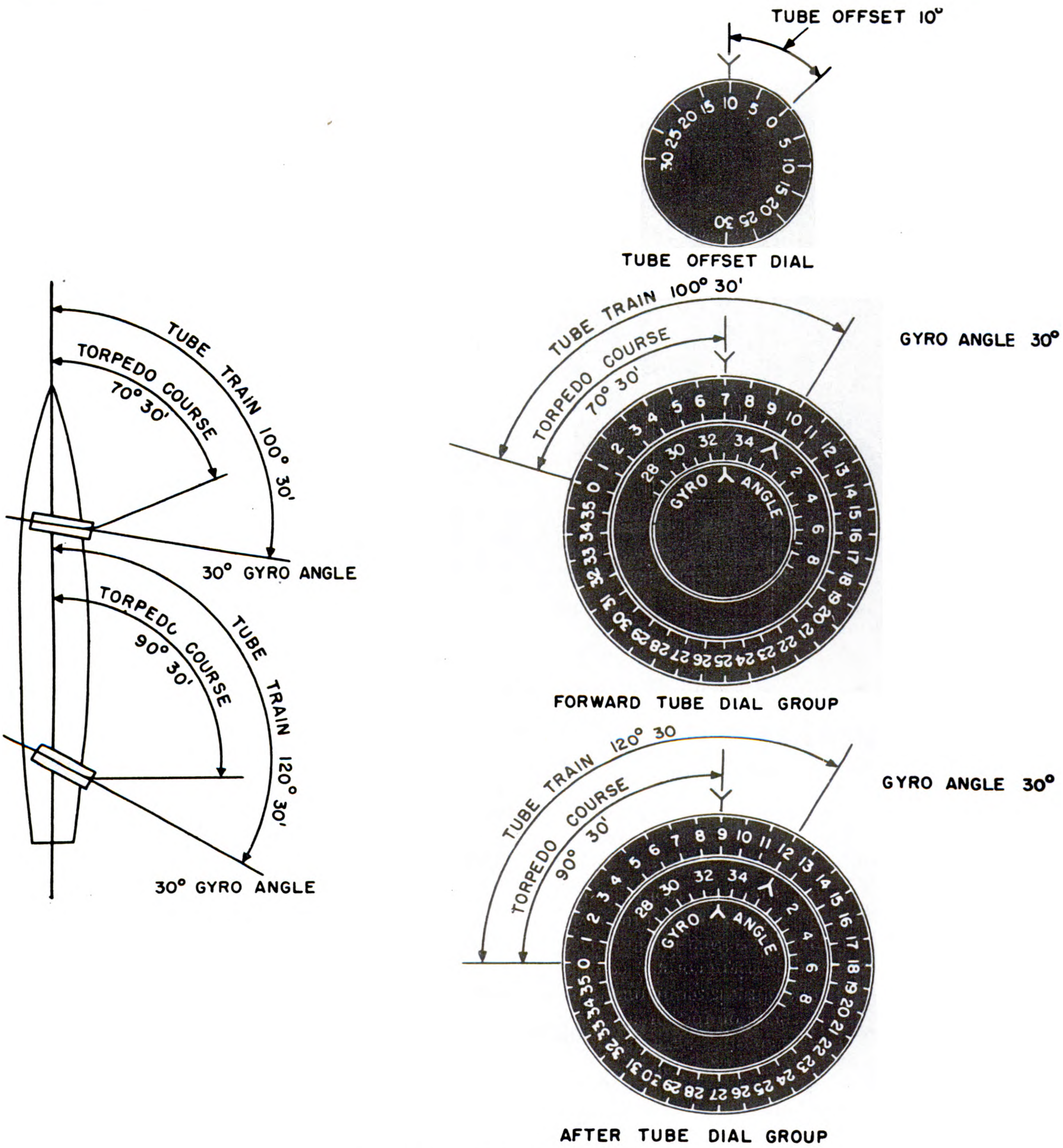


FIGURE 27C6.—Tube offset and tube dials.

27C7. Tube offset

Tube offset, *Otu,* is the angle between the tube-mount axis and basic tube train (*Bur*), measured right or left from *Bur*. Although modern destroyer torpedo installations include only one tube mount, the Mark 27 director has been built to control two tube mounts simultaneously where two mounts are installed. If a ship has two tube mounts and intends to fire the torpedoes of both mounts in a spread, it would be necessary to offset each mount from the basic tube train

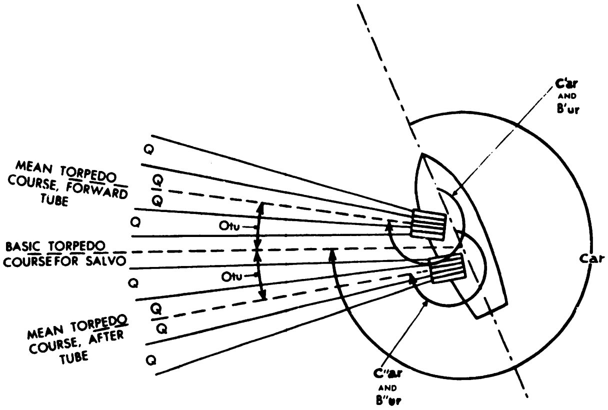

MEAN TORPEDO COURSE, FORWARD TUBE
BASIC TORPEDO COURSE FOR SALVO
MEAN TORPEDO COURSE, AFTER TUBE
Q
Q
Q
Q
Q
Q
Q
Q
Otu
Otu
C'ar AND B'ur
Car
C''ar AND B''ur

Figure 27C7.—Tube offset diagram.

Bur in order to obtain a uniform spread and prevent the torpedoes from crossing each other's tracks. The amount of tube offset will depend on the spread angle (*Q*) of the torpedoes. Tube offset is set manually on a dial (shown in fig. 27C6, upper right corner) colored half red, half green. In making setting for starboard fire, use the green sector, so that the forward tube will be offset to the left and the after tube mount to the right of the basic tube train. (To port, the opposite is true.) The single setting modifies the value of torpedo course order sent to the respective tube mounts.

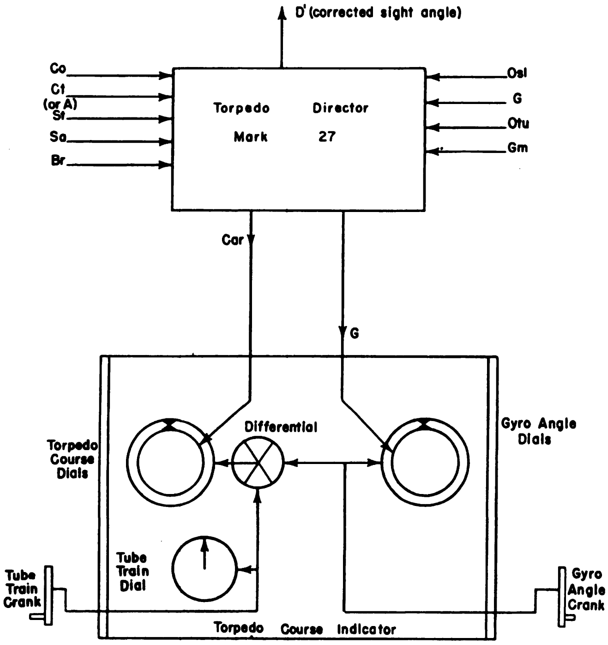


Figure 27C8.—Torpedo director system, schematic diagram.

For example, if *Otu* is 10° (based on $Q=4°$), and *Car* is 80°, then *C'ar* sent to the forward mount will be 70° and *C''ar* sent to the after mount will be 90°, as shown on the dials in the figure. (This example assumes quintuple tubes.)

On destroyers having a single tube mount, which is the normal installation, the offset dial should *always* read zero.

27C8. The torpedo course indicator

This instrument is installed on the tube mount and indicates the following values:

1. Actual tube-mount train.
2. Gyro angle ordered.
3. Gyro angle set.
4. Torpedo course ordered.
5. Torpedo course set.

Quantities 2 and 3 are compared on a follow-the-pointer dial. Quantities 4 and 5 are compared on zero-reader and follow-the-pointer dials. Referring to figure 27C9, torpedo course, received electrically from the director, positions the inner dial of the torpedo-course dials at the left. Gyro-angle order, received electrically from the director, likewise positions the inner dial of the gyro-angle dial group at the right. Matching gyro-angle order is accomplished by rotating the gyro-angle hand crank on the mount; this action also sets the gyro angle on the torpedo gyros to agree with the value transmitted by the director. This setting also goes through a differential, partially positioning the outer (ring) dial of the torpedo-course dial group. As the mount is trained, actual tube train from the auxiliary training rack positions the tube-train dial and also goes through the differential to *match* the torpedo-course dials. Thus torpedo course for torpedoes fired from a tube mount equals mount train plus gyro angle.

The *tube-train dial* is painted red in the danger sectors, and yellow in the adjacent 10° sectors, providing the tube trainer with suitable warning. If, after matching torpedo-course dials, he observes the tube train dial to be "in the red," he must train clear of the danger sector, which will cause the torpedo-course dials to become unmatched. He then orders the gyro setter to apply the necessary additional gyro angle to rematch the torpedo-course dials. This is known as "gyro-angling." Intercept offset correction for this additional gyro angle will not, of course, be applied; but when it is imperative that torpedoes be fired without delay, it is thus possible to modify a director solution which would put the tube on a danger bearing.

27C9. The Torpedo-Tube Mount Sight Mark 5

This sight, figure 27C10, installed on the tube-mount training handwheel stand, is for use in local control of torpedo fire. Its location on the tube mount is shown in figure 27C11. The sight is a combination director and aiming device and consists of two concentric rotatable plates. The upper plate carries pivoted and sliding bars which can be set to reproduce the speed triangle of torpedo fire from inputs of *A, S,* and *Sa.* These inputs offset the ***sight bar*** by the correct *D.* Then when the sight is aimed at the target, the mount is correctly trained to lead the target. Gyro angle may be introduced by rotating the lower plate to the desired *G,* moving the upper plate with it to introduce this further offset to the sight.

When *D* is computed by the Mark 27 director, its value phoned to the mount, and the tube-mount sight used only for aiming, the control is called "local aim of bridge control." In this use of the Mark 5 sight, the pivoting and sliding bars are not set up as previously described. Instead, the upper plate is rotated to the ordered *D,* offsetting the sight bar (line of sight) from the tube-mount axis.

27C10. Torpedo firing and ready light system

The purpose of this system is to provide electrical firing of each barrel, controlled from the bridge. The control features of the system are as follows:

1. *The bridge firing panel.* One bridge firing panel is installed near the director for each tube mount. It contains the tube-mount ready light and a selector switch for each barrel.

2. *The mount firing panel.* A mount firing panel is installed on the tube mount near the trainer's position. It contains a switch which closes or opens all the firing circuits on the mount. When this switch is closed, it also lights the mount ready light in the bridge panel.

3. *The firing key.* There is a firing key mounted on the director. An auxiliary bridge key may be plugged in if needed. No electrical firing can take place unless one of these keys is closed.

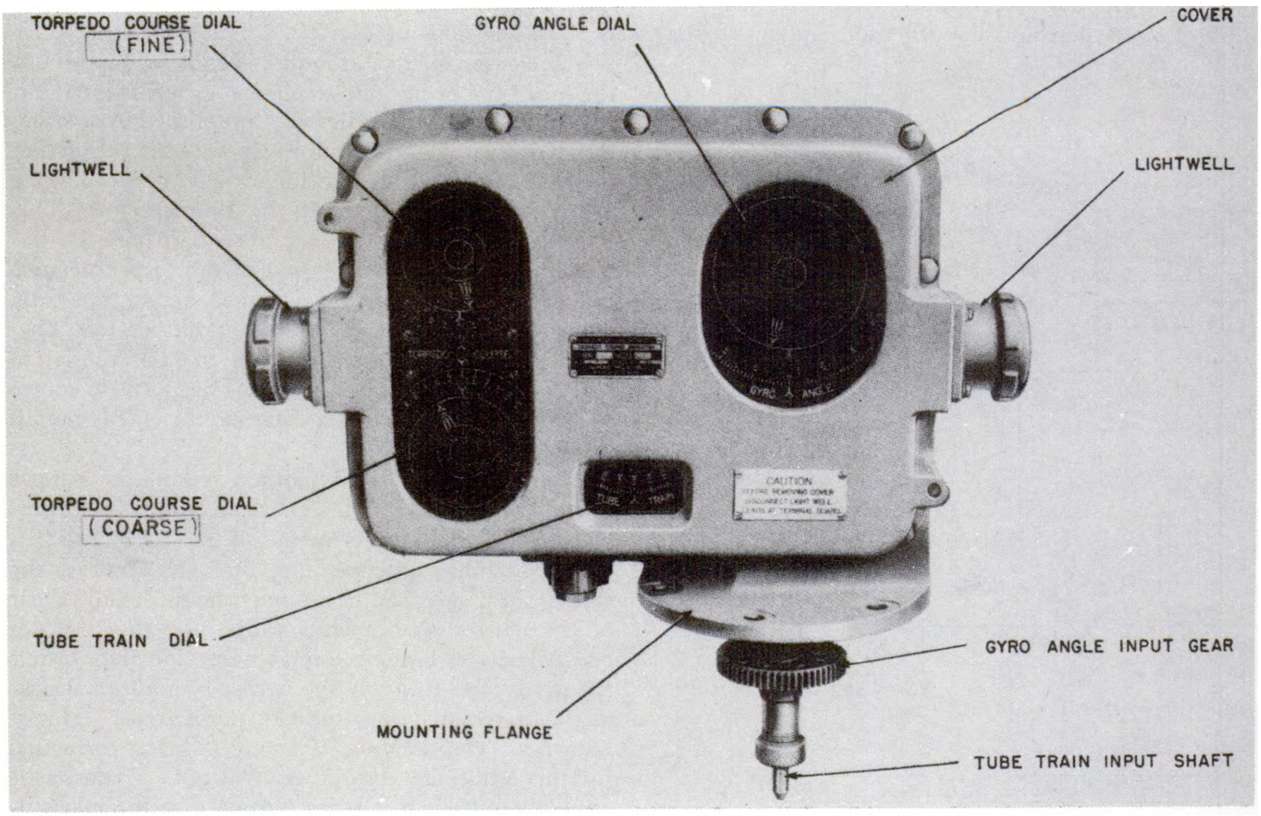


FIGURE 27C9.—Torpedo course indicator.

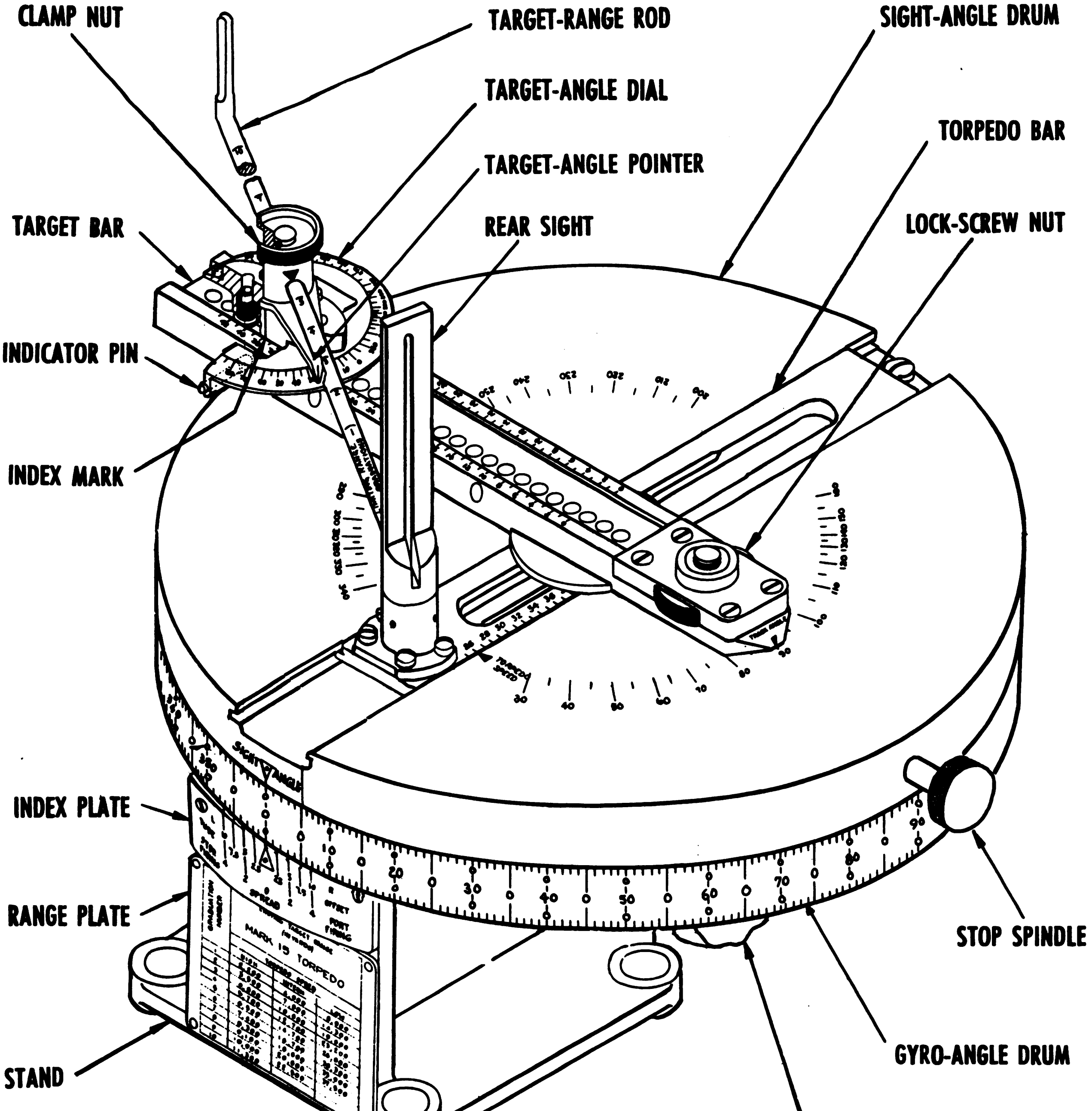


FIGURE 27C10.—Torpedo-Tube Mount Sight Mark 5.

27C11. The torpedo-tube mount

The following features of the torpedo-tube mount enter into the control problem:

1. *The gyro-setting mechanism.* This permits setting both gyro angle (G) and spread angle (Q). The gyro spindle-engaging lever is moved to the IN position, causing a vertical spindle to extend through each barrel from the bottom and engage the gyro-setting mechanism of the torpedoes. The gyro-angle hand crank is rotated until the desired angle is indicated on the gyro dials. This sets the same gyro angle, G, on each torpedo, and this value appears on the torpedo-course indicator. Another hand crank, the spread-angle setting hand crank, is rotated until the desired spread angle (Q) is indicated on a dial on the hand-wheel pedestal. This produces different gyro settings

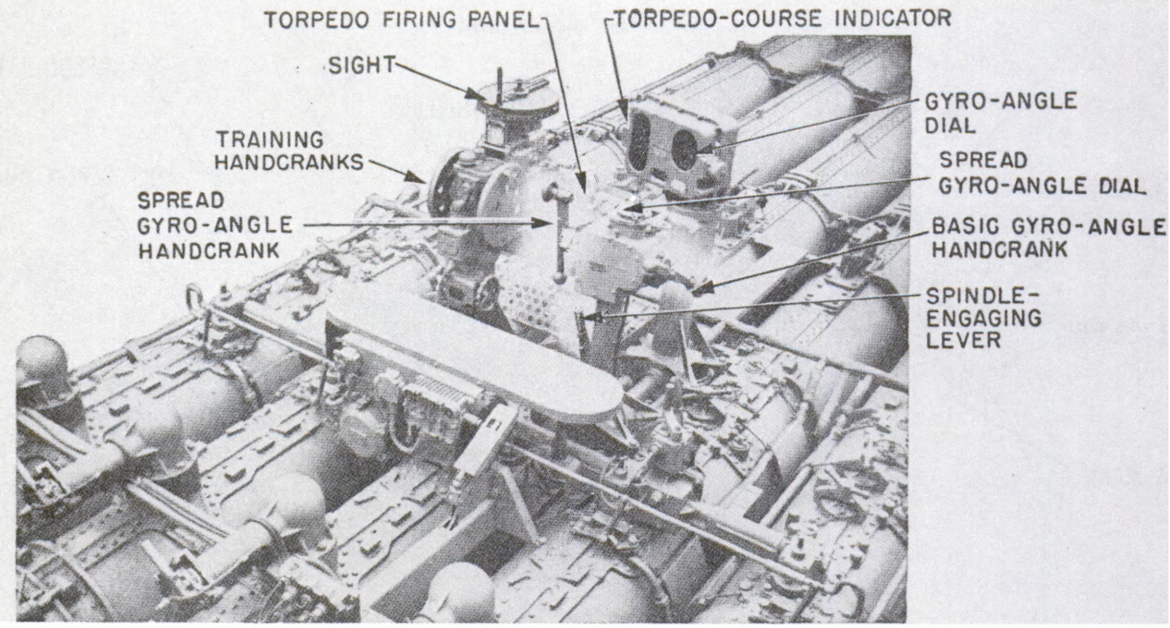


FIGURE 27C11.—Torpedo-tube mount showing controls used by trainer and gyro setter.

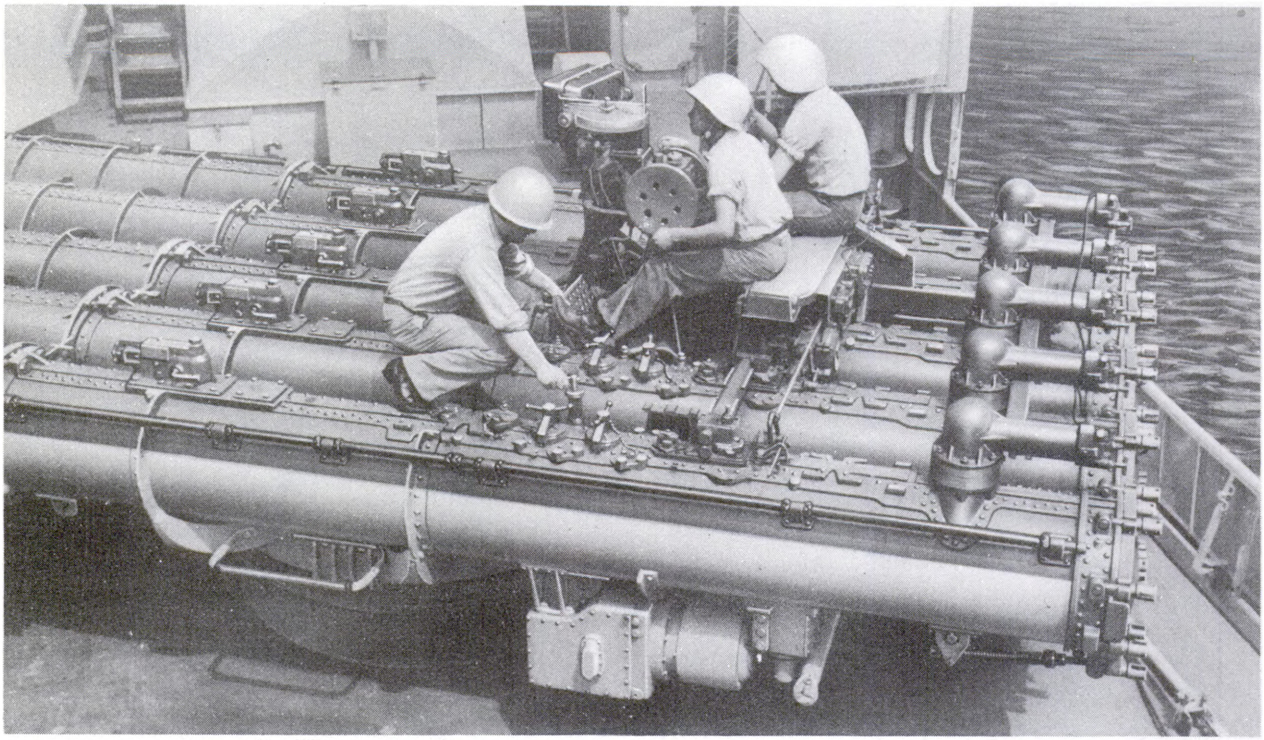


FIGURE 27C12.—Tube mount captain making a speed change.

on individual torpedoes, so that they will fan out from the center torpedo with a separation of Q degrees.

2. *The depth-setting mechanism.* This permits setting the depth at which the torpedoes are to run. The depth-setting socket lever is placed in the IN position, causing a vertical shaft, fitted with a socket on its end, to extend through each barrel from the top and engage the depth-setting mechanisms of the torpedoes. The hand crank is then rotated until the desired depth setting is indicated on the dial.

(Gyro-setting spindles and depth-setting socket levers must be in the OUT position when loading or unloading torpedoes from the tubes, and prior to launching, for obvious reasons.)

3. *Torpedo speed setting.* This is set by engaging a spring-loaded spindle in each barrel of the tube mount with the speed-setting mechanism of the torpedo. Each spindle is rotated by hand to the HIGH, INTERMEDIATE, or LOW position as indicated by the index pointer, and is then released. The spring will then automatically disengage the spindle from the torpedo speed-setting mechanism.

D. CIC's Function in the Radar-Aim Torpedo Attack

27D1. Introduction

The radar-aim, director-controlled, destroyer torpedo attack became highly developed during World War II. In any discussion of torpedo fire control, we must therefore include this type of attack and the function of CIC in making it. The line of sight to the target is established by the torpedo-director trainer, keeping follow-the-pointer bearing dials matched in the bearing repeater located on the right side of the Mark 27 torpedo director (see fig. 27C2). By means of a selector switch, target bearing may be received by this repeater either from the fire control radar, or from search radar. Fire control radar bearings are preferred, as they provide greater accuracy.

27D2. Shipboard stations active in the radar-aim torpedo attack

The conning station, main-battery director (Director Mark 37), plotting room, Combat Information Center, Torpedo Control, and torpedo-tube mount all have important functions in delivering the radar-aim torpedo attack.

CIC tracks the target, designates the target to the main-battery director, keeps Conn and Torpedo Control informed of all target movements, and checks the solution of target course and speed with the plotting-room computer solution. Initially, CIC must give Conn a course to an approach point which will put the ship in good position to make an attack. This approach point is usually a general location approximately 30° to 40° on the target's nearest bow just outside the effective range of the torpedo to be fired. Upon reaching the approach point, CIC recommends a firing course to Conn which will keep the target within effective range for a reasonable period of time and allow a firing bearing which will produce the optimum track angle of approximately 090 degrees or 270 degrees. When the ship on the firing course approaches the firing bearing, CIC so informs the captain and requests permission to fire torpedoes. Torpedo Control, on the command of CIC, fires torpedoes upon reaching the firing bearing.

In this method CIC obtains target course and speed from the DRT (dead-reckoning tracer) and figures approach and firing courses and firing bearing with the maneuvering board. The main-battery director (Director Mark 37) stays trained on the target by radar. The Computer Mark 1 in the plotting room solves for target course and speed as a check on the DRT.

27D3. Typical destroyer torpedo control set-up

The following table may be taken as typical:

DESTROYER TORPEDO CONTROL

Title	*Station*	*Duties*
Captain	Bridge	If CIC is *operative*, the commanding officer conns the ship, orders the number of torpedoes to be fired, and gives firing orders. If CIC is *inoperative*, or in case of a melee or surprise encounter, the captain designates the target, conns the ship, orders the number of torpedoes to be fired, estimates target angle and target speed, and gives firing orders.
Evaluator	CIC	CIC supplies Conn and Torpedo Control with information as to target course and speed. The evaluator also advises the captain and Torpedo Control when approaching effective range zones for own torpedoes; gives target size, if possible, so that correct depth setting may be made; and provides base torpedo course for check with Torpedo Control.

Destroyer Torpedo Control—Continued

Title	*Station*	*Duties*
Torpedo officer.....	Torpedo director..	The torpedo officer exercises control of the torpedo battery. He makes set-up on director from best available information (CIC, Mark 1 computer-Mark 37 director solution, or estimate). In case of group attack, he carries out orders of the OTC.
Torpedo control talker	Torpedo director..	The torpedo control talker acts as Torpedo Officer's talker on torpedo control circuit and operates bridge firing panel.
Director trainer.....	Torpedo director..	The director trainer maintains director line of sight on target. He fires torpedoes with director firing key and mans battle telephones on radar information circuit to receive target bearing from radar.
Mount captain.....	Tube mount......	The mount captain is in charge of the mount, where he changes torpedo speed settings as ordered.
Mount trainer......	Tube mount......	The mount trainer wears phones on the torpedo control circuit, trains mount, and repeats all orders from control to mount captain and gyro setter.
Gyro setter.........	Tube mount......	The gyro setter sets torpedo depth, basic gyro angle, and spread gyro angles. He also parallels electric firing with percussion firing.

27D4. Standard commands

The following procedure is for radar-aim, director-control, destroyer torpedo attack. It is assumed that a contact has been picked up, identified as enemy, and that the decision to attack with torpedoes has been made:

Torpedo Attack Commands

Report or Command	*From*	*To*
1. "Prepare to make torpedo attack on enemy BB (CV, CL, DD, *etc.*), bearing ————. True, range ———— yards."	Conn	CIC and Torpedo Control
2. "Torpedo action port (starboard) bridge control; match pointers."	Torpedo Control	Tube mount
3. "Pointers matched."	Tube mount	Torpedo Control
4. "Target course ———— target speed ———— knots, present range ———— yards."	CIC	Conn and Torpedo Control
5. "Target course ————, target speed ———— knots."	Torpedo Control	Torpedo director
6. "Prepare to shoot ———— torpedoes; low (intermediate, high) speed; depth setting ———— feet."	Conn	CIC and Torpedo Control
7. "Prepare to shoot ———— torpedoes; low (intermediate high) speed; unit of spread ————; depth setting ———— feet."	Torpedo Control	Tube mount and director trainer
8. "Speed set."	Tube mount	Torpedo Control
9. "Give me course at 20 (25) knots to reach approach point 30° on target's nearest bow; range ———— yards." Note: Approach point is determined by torpedo speed setting, target speed, and target angle.)	Conn	CIC
10. "Recommend course ———— to approach point."	CIC	Captain and Torpedo Control
11. "Recommend firing course ————." (Note: Upon reaching *vicinity* of approach point.)	CIC	Conn and Torpedo Control
12. "Ready to shoot torpedoes low (intermediate, high) speed."	Torpedo Control	Conn and CIC
13. "Request permission to shoot torpedoes when target bears ————°, track angle ————°." (Note: 090° or 270° considered optimum track angle.)	CIC	Conn
14. "Permission granted."	Conn	CIC
15. "Fire torpedoes"	CIC	Torpedo Control
16. "Stand by — fire one, fire two, etc."	Torpedo Control	Director trainer and tube mount

Chapter 28

ANTISUBMARINE WARFARE

A. General

28A1. Introduction

Antisubmarine warfare (ASW), consists of all measures and operations directed against enemy submarines, their operating bases, and their supporting activities. Its purpose is to deprive an enemy of the effective use of his submarines. Various types of antisubmarine operations are employed in fulfilling this purpose—some offensive in nature, some defensive. The principal ones (*i. e.*, bombing and mining, hunter-killer, escort of convoy, harbor defense, and submarine antisubmarine operations) were studied previously.

In this chapter, only operations involving surface antisubmarine (A/S) ships will be considered. The emphasis will be on the equipment actually used to detect, track, and destroy submerged enemy submarines rather than on the strategic and tactical aspects of these operations.

The importance of the surface A/S ship in antisubmarine warfare cannot be too highly stressed. Recent advances in submarine design and operation, such as greater speed and the ability to remain submerged for longer periods of time, not only have stimulated ASW research and development in all fields but have made manifest the increasing value of the surface unit as well.

It was demonstrated during World War II and has been confirmed by operational evaluation since that time that the air-surface, hunter-killer team is one of the most effective units in combating submarines directly. Aircraft are able to search large areas quickly, locate submarines, and attack them with rockets, machine guns, and depth bombs. Aircraft, however, are limited in their staying power and in their ability to maintain contact and attack once the submarine has submerged. It is at this point that the importance of surface A/S ships becomes apparent. With the submarine submerged, these ships can conduct a more effective search than aircraft because they carry sonar equipment. This equipment, to date, has proved to be the most effective means of maintaining contact with and hence controlling the attack on a submerged submarine.

28A2. Weapons

The various weapons used against submarines were discussed in chapter 14. Some of these are passive in nature and present no fire control problem. In this category are mines, and—though strictly speaking not weapons—nets and booms. Other weapons effective against surfaced submarines do not present a control problem substantially different from any other surface fire control problem. This is true in the use of guns and torpedoes of surface ships, and very nearly true of all aircraft and submarine weapons when used against submarines.

The primary antisubmarine weapons of surface vessels are depth charges and hedgehogs. Rockets and torpedoes are becoming increasingly important as antisubmarine weapons, but a discussion of their application is beyond the scope of this chapter.

28A3. Underwater detection

Echo-ranging equipment is installed on board ships to determine ranges and bearings on submerged submarines by means of ultrasonic (above audibility) sound waves. To a lesser extent, it is used for navigation purposes. In pilot waters, especially in low visibility, it may be used to locate reefs, other submerged objects, and buoys. Echo-ranging equipment is commonly referred to as *sonar,* a name derived from the long title: SOund Navigation And Ranging.

When sound waves impinge upon any submerged or partially submerged object, a portion of their energy is reflected in the manner of an ordinary echo. In sonar, these waves are projected and, in turn, received by means of a transducer located in the water forward and near the keel of the A/S vessel. The signal-receiving and -indicating equipment (the so-called stack or sonar control indicator) is located in a space known

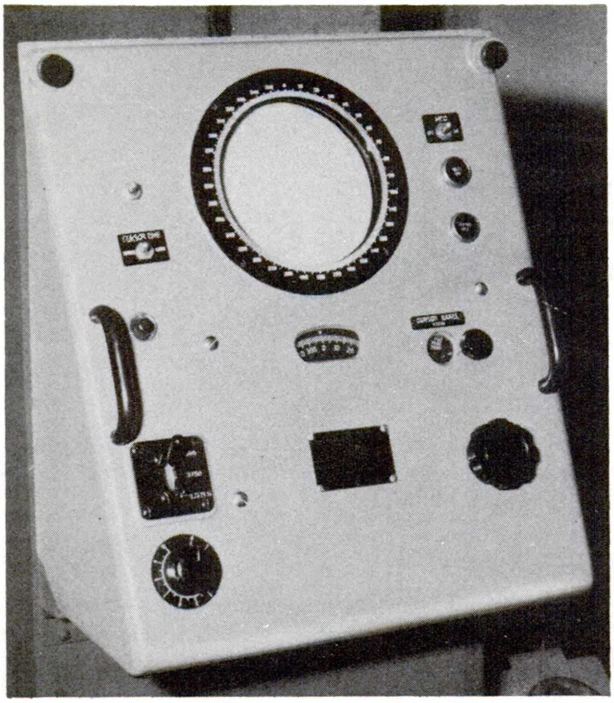


FIGURE 28A1.—The sonar control indicator.

as *sonar control.* See figure 28A1. The signal-transmitting equipment, requiring no operator, is generally installed in a space immediately above the transducer.

The principal sonars in use during World War II projected a narrow beam of sound into the water, and target indications were returned as audio responses from a speaker or headset. A thorough search was a slow process in that the operator hand-trained the transducer in increments of 2½° to 5°, according to search doctrine in force.

At the close of World War II, the Navy perfected a new type of search sonar known as *scanning* or *azimuth* search sonar (fig. 28A2). With each outgoing burst of sound, azimuth sonar searches through 360°, less a narrow sector allowed for the ship's baffles. In addition, scanning sonar offers both video and audio presentation of target information.

28A4. Limitations of sonar

The performance of sound waves when transmitted through sea water is a complex study in itself. However, a knowledge of certain features of this subdivision of physics must be kept in mind when using sonar information. Briefly the limitations of sonar are—

1. *Sound beam refraction.* Temperature and, to a much lesser extent, pressure and salinity differences cause variations in water density which, in turn, produce refraction of the sound beam. This refraction, unless corrected for, can result in serious errors in the measurement of target depth, and some error in the measurement of sonar range, and, finally, in a reduction in detection range.

2. *Speed of sound variations.* Temperature and, to a much lesser extent, pressure and salinity differences cause variations in water density which, in turn, cause variations in the speed of sound in sea water. This results in varying values of sonar range which must be taken into account since sonar, like radar, measures range by the time interval between transmitting a pulse and receiving an echo. The speed of sound in sea water at temperature 36°F and at normal conditions of salinity and atmospheric pressure is approximately 4800 feet per second. Any increase in pressure or salinity, however, will result in only slight increases in the speed of sound. The change due to salinity, moreover, is of little importance, since salinity differences normally are encountered only where large rivers empty into the sea. Any increase in temperature will result in an appreciable increase in the speed of sound.

3. *Attenuation of sound waves.* Sound waves propagated through sea water are attenuated rapidly; hence the range at which detection is possible by sonar is reduced.

4. *Echoes.* Echoes, both single and multiple (reverberations), are received from marine life, the sea bottom, and various irregularities in the fluid medium, as well as from submarines.

Although adverse water conditions may limit range and make bearing definition difficult, A/S personnel are trained to get optimum results from their equipment under all conditions. They are trained to predict sound behavior and to apply the results reliably to the antisubmarine problem. Sonarmen quickly classify a contact by its appearance on the cathode-ray scope, the quality of the sound, the bearing spread, its relative motion, *etc.* Sonar research has established certain sound "patterns," based principally on underwater temperatures. With the aid of the bathythermograph, a device for measuring water temperatures down to 1,000 feet, it is possible to predict the sound pattern and to introduce these data into the sonar system.

28A5. Antisubmarine fire control problem

The antisubmarine attack problem is similar to the surface fire control problem in that the attacking ship is considered to be moving in a horizontal plane and relative rates are computed in this plane. Antisubmarine weapons for attacking a submerged target do not have the flexibility of deck guns. Instead of computing gun orders, it is necessary to compute the course and time-to-fire in such a manner that the depth charges or throwing weapons will arrive at the predicted target position (including depth) when the submarine does.

Depth charges are either rolled off the stern of the attacking ship or projected a fixed small distance to the side. Throwing weapons are projected to a position either fixed in relation to the attacking ship or controllable within narrow limits. The fire control problem is largely a tactical problem for this reason. It is not possible to solve this fire control problem in terms of projecting the missile from *any* location of the ship to the target; instead, it is necessary to solve the problem of how to conn the ship into attack position.

In the case of depth charges this attack position is ahead of the submarine, to allow for the sinking time of the depth charges. *How far ahead* is a major variable quantity which depends on the depth of the target,

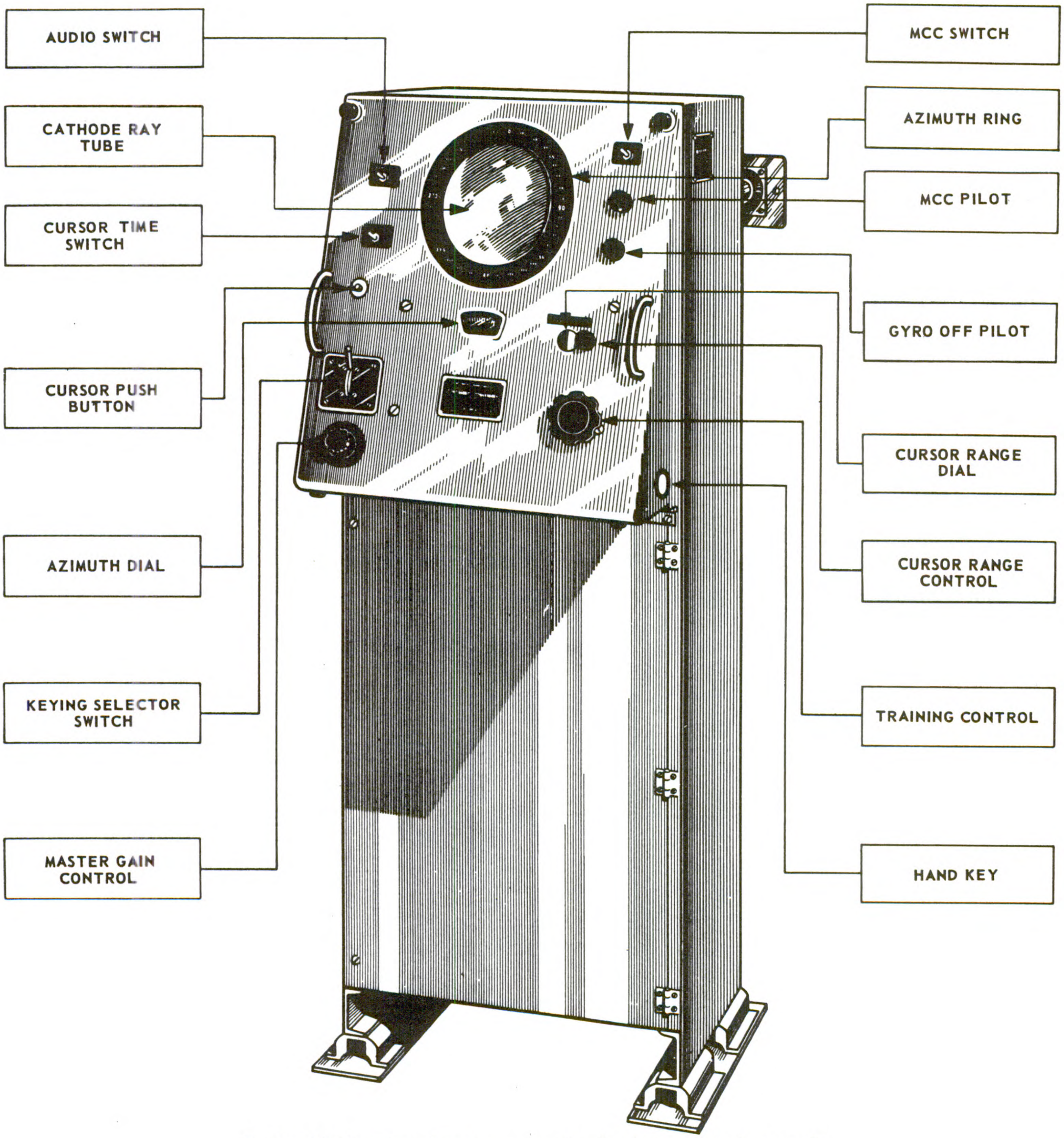


FIGURE 28A2.—Scanning sonar console, showing operator's controls.

the sinking speed of the charges, and the target course and speed.

For throwing weapons, the tactics differ. There is no necessity for passing ahead of the submarine, since the missiles are projected ahead to fall at the indicated position of the target. Sinking time is less for these missiles than for depth charges, but there is time-of-flight to be considered also. The other variables exist, but must be so calculated as to bring the target to a position off the attacking ship's bow.

The projection of throwing weapons has two great advantages over the dropping of depth charges. First, sonar contact is usually lost when the attacking ship passes over or nearly over the submarine. This must be done to reach a position ahead of the target for depth-charge attack; it is not necessary in attaining position for a throwing attack. Second, hydrostatic depth charges explode whether close to the target or not, and the explosion causes a disturbance of the water which interferes with sonar; throwing weapons explode on contact only, so misses do not interrupt sonar contact. (This second advantage is being offset by increased use of influence-type depth charges such as the Mark 14.)

Depth charges may be dropped from the racks at the stern, or fired from side throwers (K-guns) which hurl them as far as 125 yards on the beam. Ships lacking side throwers, of course, can drop charges only along a straight line; but if K-guns are installed any one of several standard patterns may be fired. The type of pattern depends upon the situation and the number of throwers.

While the attack is always calculated with reference to one charge—the center one of the pattern—the extensive possibility of an error makes the use of additional charges necessary. Therefore they are ordinarily dropped in patterns. When hydrostatic charges are employed, they are set to explode at variouse depths in the water beneath the surface area covered by the pattern.

Explosives fired under water can do greater damage than a corresponding amount of explosive set off in the air. Nevertheless, modern submarines are so strong that a charge must explode close aboard to have conclusively destructive effect.

Explosions beyond the lethal range may indirectly cause destruction of the submarine through leaks in the hull, jamming of the hydroplanes, or other forms of damage.

The depth-charge pattern is a plan for dropping depth charges. There are two major patterns, known as *urgent* and *deliberate*.

The *urgent* pattern is laid to harass the sub and prevent accurate torpedo fire. It consists of one or more charges fired immediately, with shallow settings, in an attempt to drive the submarine down and prevent it from firing torpedoes. Hydrostatic charges are always used.

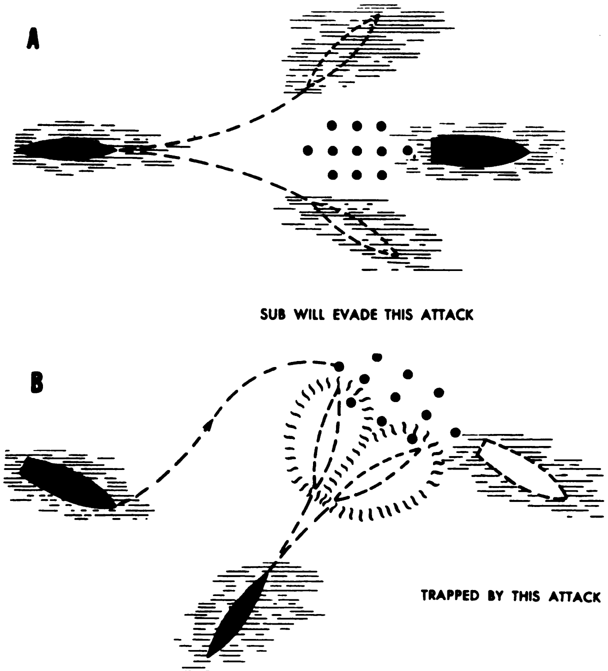


FIGURE 28A3.—Depth-charge patterns.

The purpose of a *deliberate* attack is to destroy the submarine. The pattern is dropped in such a way that the center charge of the pattern will explode against the submarine. The deliberate pattern is the standard full pattern of charges fired by the attacking vessel.

The chief difficulty with any attack is the time required for the charges to sink. The obsolescent 750-pound depth charge, for example, requires about 40 seconds to reach a depth of 250 feet. During this time the submarine can maneuver without interference. In 40 seconds an 8-knot submarine can travel 180 yards, make a 60° turn, and even change its depth by 60 feet.

There is a repetition of the situation encountered in gunfire. Unless the submarine is stationary, the charges can no more be dropped directly over it than a gun can be fired directly at a moving target and score a hit.

If the sub is moving straight along the attacking ship's path, it is a simple matter to compensate for the sinking time of the charges. If the attacking ship is approaching the sub head-on, it may drop the charges before passing over the sub.

In both direct bow and stern attacks, the submarine commander has a good chance to evade the attacking ship—and he will, if possible. Sonarmen aboard the sub can hear the attacking ship, and the submarine will rarely move along the ship's track.

If a pattern were laid as shown in part A of figure 28A3 the sub could evade by turning in either direction. The antisubmarine vessel, therefore, must counter the sub's evasive tactics by a maneuver similar to the one shown in part B of figure 28A3. Even though the sub tries to turn, it will come in contact with one of the charges of the pattern.

When sonar contact is made and direction of target movement is established, the antisubmarine ship is brought to a course which will take it across the bow of the submarine and sufficiently far ahead to allow for the sinking time of the charges. Thus the depth charges will explode at the same time the sub reaches them.

In order to steer the proper course, the conning officer must know the range and also the approximate bearing, course, speed, and depth of the sub. Even with all this information, the attack course selected is subject to change at any moment because of the sub's maneuvers. Unfortunately these maneuvers may go undetected. At very short ranges, 150 yards or less, the return echo of the sonar equipment cannot be distinguished from the outgoing signal. Also, contact may be lost at longer ranges; for example, contact may be lost at 700 yards if the sub is deep enough. Thus the sub's position will often not be known exactly in the last stages of the attack.

To reduce both the length of this "silent period" and the chances of evasion by the sub, the surface vessel generally attacks at as high a speed as possible. (The conning officer must also make certain that his ship will clear the explosions of the stern-dropped charges.) The maximum attack speed, however, is limited. At high speeds the water noises caused by the sonar transducer traveling through the water may obscure the sound echoes from the sub.

28A6. Throwing weapons

During an attack with throwing weapons, the sonar operator must hold contact with the sub and furnish the conning officer with continuous ranges and bearings. The conning officer then keeps the ship headed toward the target and comes in for the attack. Because the charges have a fixed range, the pattern must be fired when the ship reaches the correct firing range. The correct firing range depends upon many factors, most of which are calculated in advance and set into the range recorder, attack plotter, and OKA equipments.

28A7. Conclusion

Other types of weapons and other forms of attack are under development, but their security classification is such that they cannot be considered in this text.

B. QHBa Scanning Sonar Equipment

28B1. QHBa scanning sonar equipment—general

The sonar equipment in most general use in the fleet at the present time is the scanning sonar equipment, model QHBa. This will be the only equipment discussed in this text. Model QHBa combines both echo-ranging and listening equipments in one unit. On a cathode-ray tube (CRT) scope, similar to a radar PPI-scope, it provides a continuous visual display of echo reception from all directions in azimuth, and an audible response from any desired single direction.

The QHBa equipment consists of the following five major units:

1. Indicator control.
2. Transmitter-receiver.
3. Transducer.
4. Scanning switch assembly.
5. Data converter.

These units, their functions, and their operation will be discussed in detail in the articles following.

28B2. QHBa indicator control

The QHBa indicator control, as its name implies, controls the operation of the QHBa equipment and provides for the video and audio presentation of target echoes.

1. *Video presentation.* At the instant that a pulse of sound energy is projected into the water in all directions, a luminous spot on the CRT-scope (*i. e.,* the trace of the electron beam) begins to spiral outward from the center. This spiraling motion is in reality a combination of two motions. One, a straight-line movement of the spot toward the periphery of the scope, is called the *linear sweep.* The other, a circular movement of the spot about the center of the scope, is known as the *circular sweep.* The linear sweep occurs at a relatively slow rate of speed which is proportional to half the speed of sound in sea water. The circular sweep, on the other hand, occurs at a relatively high angular rate (1750 rpm). The result is that the QHBa operator observes the motion of the electron beam trace or spot not as a spiral but rather as an expanding circle of constantly increasing radius.

When the outgoing pulse of sound energy strikes a submerged object such as a submarine, part of its energy is reflected as a target echo. This echo, after being received, changed into an electrical signal, amplified, and rectified, is applied to the control grid of the cathode-ray tube and hence appears as a bright spot or pip on the CRT-scope. Because of the persistence of the scope, this pip, along with other target pips, remains on the scope long enough to be reinforced by another returning echo. The result is a map-like presentation which is invaluable in target detection.

Once a pip appears on the CRT-scope, its range and bearing can be ascertained easily. Inasmuch as the CRT beam trace moves linearly outward from the center of the scope at a speed proportional to half the speed of sound in sea water, the distance of a target pip from the center of the scope is a measure of sonar range Rq. Similarly, since the scope is so oriented that true North is at the top with own ship at the center, the angular displacement of the pip from the top of the scope is the true sonar bearing Bq of the target. See figure 28B1.

The direction of the audio scan (*i. e.,* the direction in which the QHBa equipment is trained to receive an audible echo) is indicated on the CRT-scope of the QHBa indicator control by a bright line called a *cursor*. This cursor flashes on the scope at the instant the outgoing sound pulse is transmitted. The cursor's length is adjustable. Therefore it can be seen that, by bisecting the target pip with the cursor and then adjusting the length of the cursor so that its outer tip just touches the pip, the cursor bearing will be the true sonar bearing Bq and the cursor length will furnish an indication of sonar range Rq.

On the CRT-scope, a dotted line indicates the true direction of the stern of the ship (*i. e.,* ship's head plus 180°) so that, at any time, the relative location of a target as well as the direction of the baffles can be ascertained. To prevent interference with the visual presentation of a target pip during an attack, the dotted line extends out in the direction of the ship's stern.

2. *Audio presentation*. The returning echo, after conversion to an electrical signal and amplification, also is changed to an audible frequency and sent to a loudspeaker near the QHBa indicator control, where it is heard as a sharp "ping." This ping is of value in target identification and in the determination of *doppler*.

Up doppler is the increase in frequency of returning sound wave caused by a target's true motion toward own ship. *Down* doppler is the decrease in frequency of returning sound waves caused by a target's true motion away from own ship. A target which causes up doppler is said to have bow aspect, while a target causing down doppler has a stern aspect.

3. *Controls*. Figure 28A2 shows the various knobs, switches, *etc.,* on the control panel of the QHBa indicator control. Collectively, they are used to operate all the scanning sonar equipment.

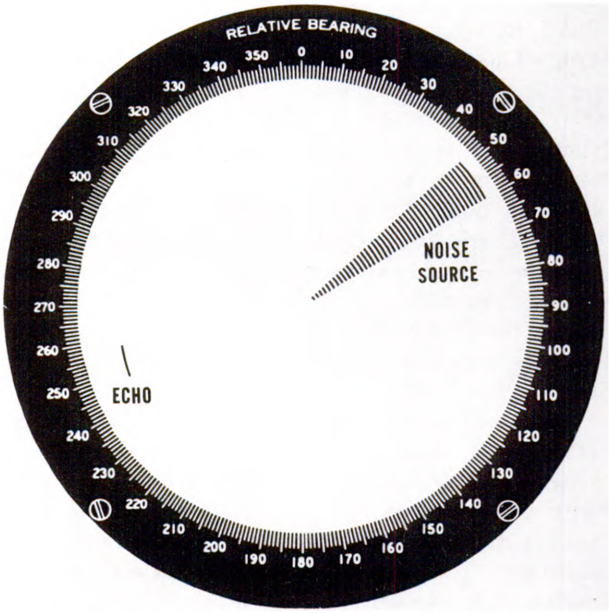


FIGURE 28B1.—Typical noise source bearing 054°, and echo source bearing 253°, at range 1400 yards.

a. Bearing knob and bearing dial. The true bearing of the cursor (and hence of the audio scan) is controlled by the bearing knob and is indicated on the bearing dial. The knob, when turned, will change the cursor bearing at a relatively slow rate. However, if the knob is pressed in and rotated one-eighth of a revolution in either direction, the cursor will slew rapidly. As explained previously, if the cursor is positioned so that it bisects a target pip, the cursor's bearing will be the true sonar bearing Bq of that particular target. Bq can be read on the bearing dial.

b. Range knob and range dial. It was noted above that the length of the cursor (and hence cursor range) could be varied. The range knob is the control which determines this length. It is located directly above the bearing knob and has adjacent to it a range dial on which approximate values of cursor range can be read. Again, if the outer tip of the cursor just touches a target pip, the value of range indicated on the range dial will be an approximate value of sonar range Rq to that particular target. Such a value, of course, is of interest only when making an initial contact report. Accurate values of Rq, as will be explained later, are determined by the OKA–1 range recorder for use in the antisubmarine fire control problem.

c. Keying selector switch. This switch has three positions: 1500, 3750, and LISTEN. When it is moved to the position marked 3750 (during search and when tracking a target at a range greater than 1500 yards), the scale of the CRT-scope (*i. e.,* the distance from the center of the scope to the periphery) becomes 3750 yards. Similarly, when the keying selector switch is moved to the position marked 1500 (when tracking a target within 1500 yards), the scale of the scope becomes 1500 yards. In each of these cases, the video sweep (*i. e.*, the expanding circle) moves all the way out to the periphery of the CRT-scope before collapsing and starting anew from the center. Thus it can be seen that the keying selector switch controls not only the range scale of the CRT-scope but also the time between successive sweeps. Finally, when the keying selector switch is set on LISTEN, automatic sound-pulse transmission is stopped, underwater signaling by means of a hand key is possible, and the direction of ultrasonic-frequency noise sources can be determined by observing the bearing of radial patterns on the CRT-scope which represent acoustic signals from those sources.

d. Cursor push button and cursor time switch. These controls determine the duration of cursor illumination. The cursor push button is pressed whenever it is desired to have the cursor remain lighted on the CRT-scope (in order to determine accurately the bearing of a target, for example). The cursor time switch is used to control the duration of the cursor "flash"; if moved to the SHORT position (the normal position during search), the cursor will appear only momentarily when the video sweep begins to move out from the center of the CRT-scope; if the switch is moved to the LONG position (the normal position during attack), the cursor will remain on during the scan period until shortly before the echo is expected to appear (until the video sweep is 200–300 yards short of the pip position).

e. Other controls and indicators. The GAIN control adjusts the gain of both the video reception (the pip) and the audio reception (the ping) simultaneously. The AUDIO switch enables the operator to improve the signal-to-noise ratio (and hence the sharpness of the pip) whenever a noisy target is encountered. The MCC switch (an ON-OFF switch) is used for maintenance of close contact; that is, when moved to the ON position it causes the sound beam to be broadened vertically to permit tracking of targets at closer ranges. The MCC pilot light becomes lighted whenever the MCC-switch is on. The GYRO OFF pilot light, when illuminated, indicates that the top of the CRT-scope represents own ship's bow rather than true North, because of a gyro failure.

The mark signal switch and the aided tracking switch, located on the left and right sides of the control panel, respectively, are used in conjunction with the attack director and therefore will not be described here.

28B3. QHBa transmitter-receiver

At the instant the video sweep begins to move outward from the center of the CRT-scope, the keying circuits of the QHBa indicator control send a signal known as the *keying pulse* to the QHBa transmitter-receiver. This pulse initiates operation of the transmitting circuits in the latter unit. The transmitting circuits, in turn, produce a high-voltage pulse of electrical energy at a proper supersonic frequency (about 25.5 kc) and transmit this pulse *via* the scanning-switch assembly to the transducer.

Returning echo signals from the transducer, on the other hand, after passing through the scanning-switch assembly, come to the receiver circuits of the QHBa transmitter-receiver, where they are amplified to a suitable level for audio and video presentation. The video signals, moreover, are rectified in order that they may be applied directly to the control grid of the CRT-scope in the QHBa indicator control for screen brightening. And the frequency of the audio signal is changed to a sonic or audible frequency, so that it may be heard over the loudspeaker used in conjunction with the QHBa indicator control.

28B4. QHBa transducer

This unit is mounted in a sound dome below the hull of the ship. Its functions, briefly, are—

1. To convert the pulse of electrical energy received from the transmitter-receiver into a pulse of acoustic energy of the same frequency, and to project this pulse into the surrounding water in all directions in azimuth.
2. To receive the returning echoes and to convert them into electrical energy of the same frequency.

These functions, it can be seen, are similar to those performed by the antenna of a radar.

The transducer proper, shown in figure 28B2, consists of 48 staves mounted around the periphery of a circle in much the same manner as the staves of a barrel. The staves, in turn, are separated from the surrounding water by a rubber jacket. The composition of this jacket is equivalent to the density of sea water, so that any vibration of the staves is transmitted unaltered into the surrounding water.

Each stave consists of four elements. The lower three elements are of the same size and are used with their counterparts in the other staves to form the normal sound beam. The upper element is shorter than the other three. It is used with its corresponding elements in the other staves to form a beam which is broadened vertically and which, consequently, is desirable for the maintenance of close contact. The upper elements are used when the MCC (maintenance of close contact) switch is on.

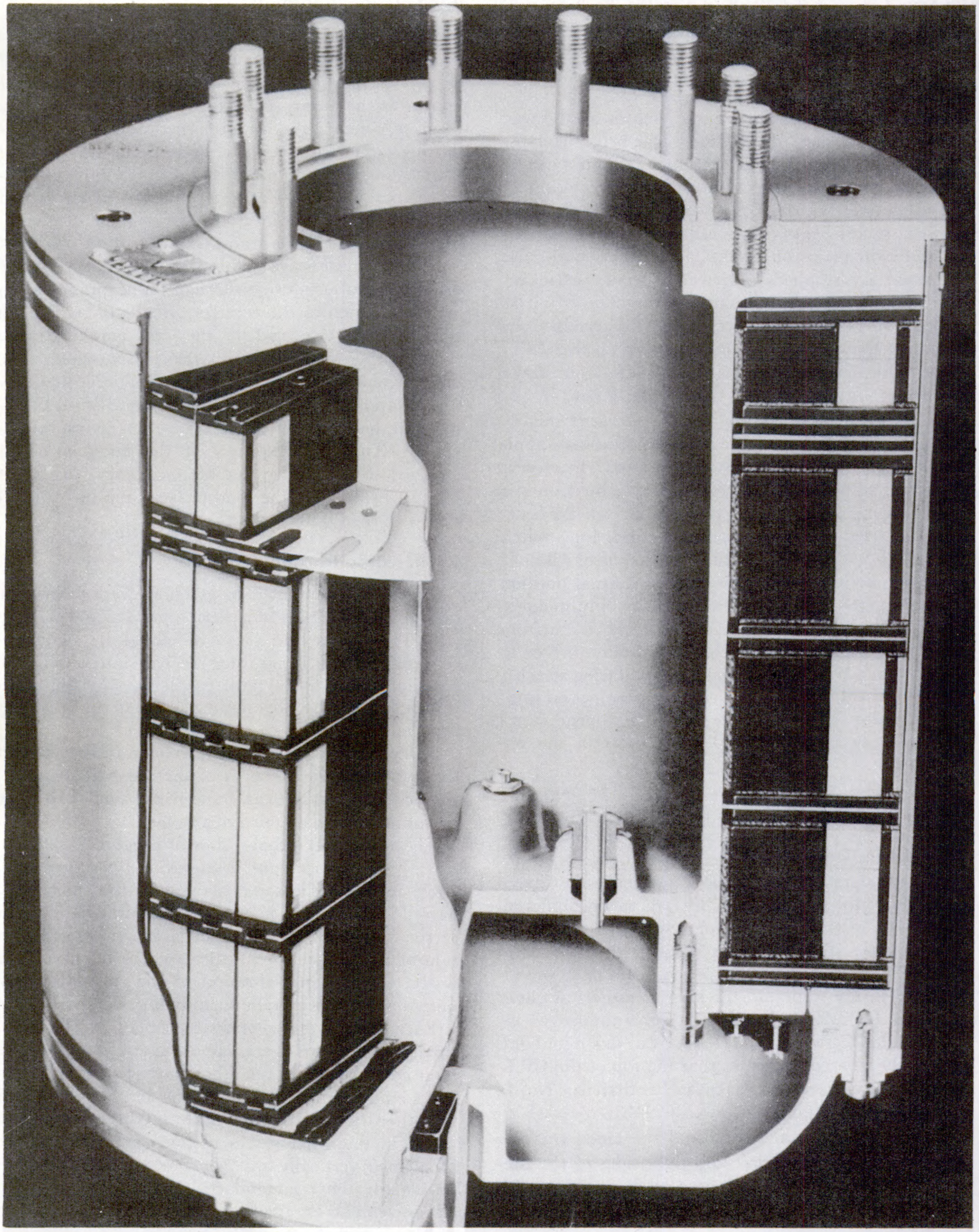


Figure 28B2.—The scanning sonar transducer.

All the staves are made of a nickel alloy which has the property of vibrating whenever an alternating magnetic flux penetrates it. This property is known as magnetostriction. Each element of a stave is surrounded by a coil. During transmission, this coil receives an alternating current from the QHBa transmitter-receiver. When this current passes through the coil, an alternating magnetic field is produced which penetrates the element of the stave, causing it to vibrate and hence produce a sound wave. The magnetic field is so adjusted that the frequency of this vibration is the same as the frequency of the applied current.

Once the sound pulse has been transmitted, the transducer staves act as microphones; and, upon receipt of a returning echo, the sequence of the events outlined above is reversed. The acoustic echo causes the staves to vibrate; and the vibrating staves, in turn, cause electrical currents to flow through the coils and hence to the transmitter-receiver.

28B5. QHBa scanning-switch assembly

The QHBa scanning-switch assembly determines the bearings of returning echoes and hence of sonar contacts. It is installed electrically between the QHBa transmitter-receiver and the QHBa transducer, and therefore controls both the outgoing sound pulse and the returning echo. There are two scanning switches in this assembly, the video scanning switch and the audio scanning switch, each of which operates independently of the other. Essentially both are the same, mechanically and electrically.

1. *Video scanning switch.* The video scanning switch consists basically of two metalized glass discs separated by a narrow air space. One disc is called the stator; the other, the rotor. The rotor and stator have 48 aluminum capacitor segments each, equally spaced about their peripheries. Each of the 48 segments of the stator is connected electrically to a corresponding stave of the transducer. On the rotor, 30 of the 48 segments are shorted out so that, in effect, there are only 18 active segments (*i. e.,* 18 segments that can receive electrical signals from the stator). The stator of the video scanning switch is fixed. The rotor, however, is rotated at a constant rate of 1750 rpm. Consequently, target echo signals received from the 48 staves of the transducer by the 48 segments of the stator can be sampled consecutively, 18 at a time, by the rapidly rotating 18 active segments of the rotor. This sampling (or scanning, as it is called) provides video indication of the sonar bearings of all targets within a 360° arc in azimuth (as will be explained below).

2. *Audio scanning switch.* This switch has essentially the same construction as the video scanning switch. However, its rotor, instead of being rotated continuously, is positioned in any desired direction by the bearing knob of the QHBa indicator control. Hence the 18 active segments of this rotor will sample echo signals from only 18 stator segments (and hence 18 transducer staves) when positioned in any one desired direction. This sampling (or scanning) provides an audio indication of the sonar bearing of any one particular target.

3. *Bearing determination.* If the QHBa scanning sonar equipment were to employ a plane transducer (*i. e.,* one with a flat transmitting/receiving surface) instead of its cylindrical one, this plane transducer would be able to transmit a sound pulse in (and hence receive a returning echo from) only one particular direction at any one time. The sonar bearing of the target echo in such a case, consequently, could readily be ascertained by noting the direction in which the transducer was trained. However, echo-ranging with such a transducer would be a slow process, nearly inadequate for effective 360° search. Therefore the QHBa employs the cylindrical type of transducer described earlier in this article. This cylindrical type not only can transmit a sound pulse in every direction in azimuth simultaneously, but it can receive returning target echoes from any direction at any time between transmissions. This naturally makes possible the early detection of all targets within sonar range. Since the receiving transducer surface is cylindrical and hence nondirectional, the direction from which a target echo is received cannot be measured by some simple method such as training the transducer itself. The video and audio scanning switches are used for this purpose.

Whenever a sound wave strikes a submerged submarine, part of its energy is reflected as an echo. This echo, upon leaving the target, fans out in several directions at once. By the time it arrives at the transducer it has, for all practical purposes, a plane front (*i. e.,* a straight leading edge). The transducer stave nearest the target in bearing consequently receives an acoustic echo signal sooner than its adjacent staves. The video and audio scanning switch stator segments connected to this stave receive, as a result, electrical echo signals (suitably amplified by the preamplifiers of the scanning-switch assembly) sooner than their respective adjacent segments. Thus the reception of all electrical echo signals by the stators is comparable to the reception of all acoustic echo signals by the transducer. Consequently, for purposes of target bearing determination, only the stators need be considered.

It was pointed out previously that the sonar bearings of a target could not be measured readily by a cylindrical transducer because of its curved surface and hence nondirectional characteristics.

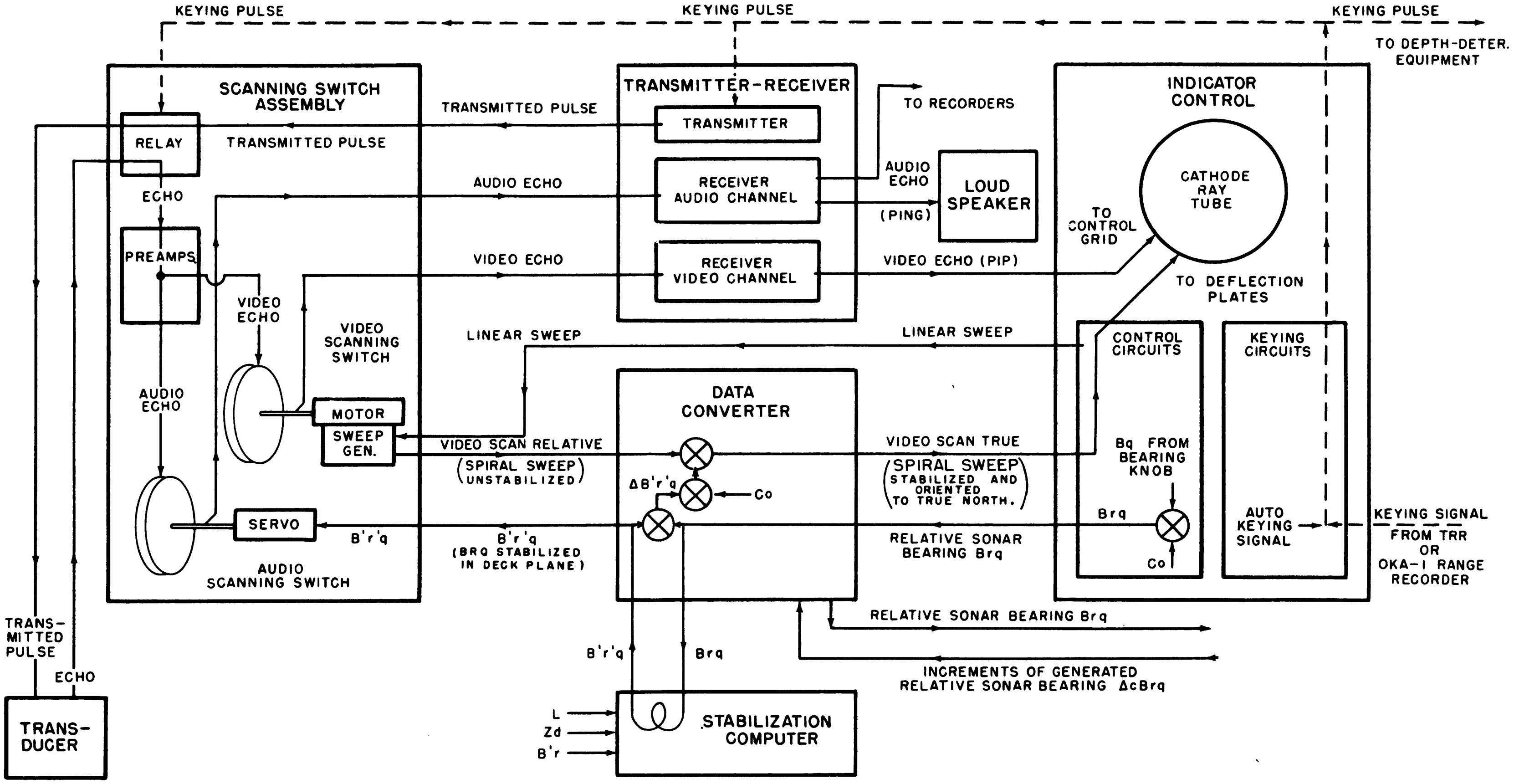


FIGURE 28B3.—Operation of QHBa scanning sonar equipment.

The 18 active segments of the rotor are made to act as a plane transducer by the use of *lag lines.* The direction of the 18 active segments when the signal is received gives the bearing of the target. A similar set of lag lines can be found on the audio scanning-switch rotor. As the 18 active rotor segments of either the video or the audio scanning switch are positioned opposite any 18 segments of the appropriate stator, electrical charges on the stator segments jump the narrow air space to the active rotor segments and enter the lag lines.

The lag lines effectively "slow down" these electrical signals proportionally so that all the signals, despite their times of receipt, leave the lag lines at the same instant. In other words, the lag lines combine the voltages of these signals in the proper manner (by shifting them into phase with one another and by appropriate attenuation) to produce a total voltage which will be a maxirum when the angular position of the rotor (*i. e.,* the midpoint of the arc formed by the 18 active segments) corresponds to the actual direction of the target.

In the case of the audio scanning switch, this total voltage is sent to the receiver audio channel in the QHBa transmitter-receiver, where it is used to produce the audible "ping." In the case of the video scanning switch, the total voltage is delivered to the receiver video channel in the QHBa transmitter-receiver, where it is amplified and rectified for use in the QHBa indicator control as a brightening signal. Since the circular sweep of the CRT-scope in the QHBa indicator control is synchronized with and hence rotates at the same speed (1750 rpm) as the video scanning switch rotor, this brightening will occur at the correct bearing on the CRT-scope.

28B6. QHBa data converter

This unit has two functions. For one thing, it orients the visual presentation on the CRT-scope of the QHBa indicator control so that the top of the scope represents true North rather than own ship's bow. Thus, for any target, true sonar bearing (*Bq*) rather than relative sonar bearing (*Brq*) is indicated on the scope.

The QHBa data converter performs its second function in conjunction with the stabilization computer. Together these two units stabilize (1) the visual CRT-scope presentation (by stabilizing the circular sweep), and (2) the audible loudspeaker reception (by stabilizing the training signal to the audio scanning-switch rotor). The result is that, as the ship rolls and pitches, the target pip on the CRT-scope will not shift its position, and the target ping from the loudspeaker will not be diminished in intensity because of the deck inclination. These corrections correspond to deck-tilt corrections in the gunnery system.

28B7. Keying circuit

The keying circuit controls the transmission of the sound pulse. This keying circuit may be controlled automatically by the QHBa indicator control (with the keying selector switch), or remotely by either the OKA-1 range recorder or the tactical range recorder. Whenever this circuit initiates a pulse, it accomplishes various functions almost simultaneously. These are—

1. It sends a pulse to the transmitting circuits of the transmitter-receiver which, in turn, send a high-voltage pulse of electrical energy *via* the scanning-switch assembly to the transducer.
2. It sends a signal to the scanning-switch assembly to operate a relay which cuts out the receiving circuits of the transmitter-receiver during the time the outgoing pulse is being transmitted.
3. It collapses the previous video sweep from the CRT-scope and starts a new one by sending a linear sweep voltage to the sweep (synchro) generator of the video scanning switch; in the sweep generator this voltage is combined electrically with rotor rotation (1750 rpm) and returned to the CRT deflection plates as a new video (spiral) sweep.
4. It causes the cursor to flash on the CRT-scope.
5. It sends a signal to the depth recorder which starts the stylus excursion across the chart paper.

28B8. Summary

Figure 28B3 illustrates, in simplified schematic form, the operation of the various units of the QHBa scanning sonar equipment.

C. Controlling the Attack

28C1. General

Sonar can search out the target, but course-to-steer and firing time must be determined by other instruments. Two such instruments, widely in use by the fleet, are the *tactical range recorder* (TRR) and the *antisubmarine attack plotter* (AP).

28C2. Tactical range recorder (TRR)

The tactical range recorder (TRR) produces a time/range plot of target echoes on chemically sensitized paper by means of a moving stylus. See figure 28C1. The stylus moves across a chart at a speed proportional to half the speed of sound in water and

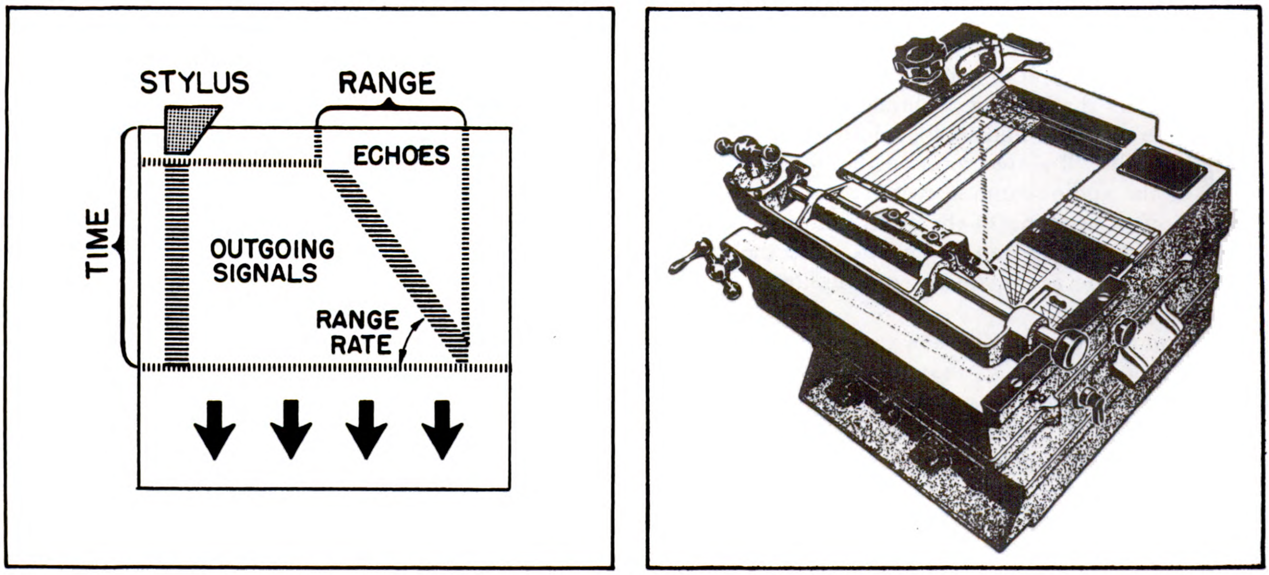


FIGURE 28C1.—The time range plot and the tactical range recorder.

the chart paper moves at a constant speed in a direction perpendicular to the stylus motion. The tactical range recorder accomplishes the following functions:

1. It provides a visible plot of the audio reception to help identify target echoes.
2. It may be used to control the keying circuit of the QHBa scanning sonar equipment.
3. It provides a means for measuring sonar range *Rq* and sonar range rate.
4. It provides a means of determining firing time (*i. e.*, the time when $Tud=0$) for either the stern-dropped (depth-charge) attack or the throwing-weapons (hedgehog) attack.

The TRR has two range scales. On *long* scale the entire width of the chart paper represents 0–3750 yards, while on *short* scale it represents 0–1500 yards. (Both the QHBa indicator control and the OKA–1 range recorder have the same scale arrangement.) In order to measure sonar range *Rq* and sonar range rate for both scales, using the same chart paper, it is necessary to have a range scale, stylus speed, and chart-motion speed for each scale. Refer to figures 28C2 and 28C3. The 0–3750 yards range scale is etched on a black metal plate on the top of the recorder above the window over the chart. The 0–1500 yards scale (not shown in the illustration) is inside the window just above the chart, and is etched on clear lucite and illuminated by an inside light.

A *gear-changer lever* (shown in fig. 28C2) on the right side of the recorder selects the proper stylus and paper speed for each scale. Just above the top of the chart paper is a pointer commonly called the *flyback*, whose position across the chart is controlled by the *flyback lever* (not shown in illustration) on the front of the TRR. When the stylus reaches this flyback, it stops its recording stroke and is returned quickly to the left to start another recording excursion.

The recorder sends a keying signal to the QHBa scanning sonar equipment at the instant it starts its recording motion. The position of the flyback therefore determines the keying interval of the QHBa scanning sonar equipment. Current doctrine requires that flyback position should be the range to the target plus 200 yards, except that it should not be moved closer to the zero range position than 500 yards.

On top of the recorder is a plotter bar which is rotatable and has a lucite extension on which are etched a series of lines parallel to the plotter bar. See figure 28C3. By aligning one of these lines with the traces on the chart, the slope of the range line and hence the sonar range rate may be measured. This plotter bar is also used to determine firing time (discussed later).

As will be seen in figure 28C3, there are several scales used to set in the various values concerned with determining the time to fire a hedgehog barrage or depth-charge pattern. The majority of these scales are set for certain physical characteristics of the ship and are not changed as the attack progresses. These are—

1. *Bow firing-lag scale* (*inscribed* FIRING LAG SEC.). On this scale is set the total time interval between the moment the A/S officer orders "Fire" and the instant the hedgehogs hit the water—dead time (*Tg*) plus time of flight (*Tf*). The dead-time factor in this setting is determined by a time study on each ship; the time-of-flight factor, from appropriate range tables.

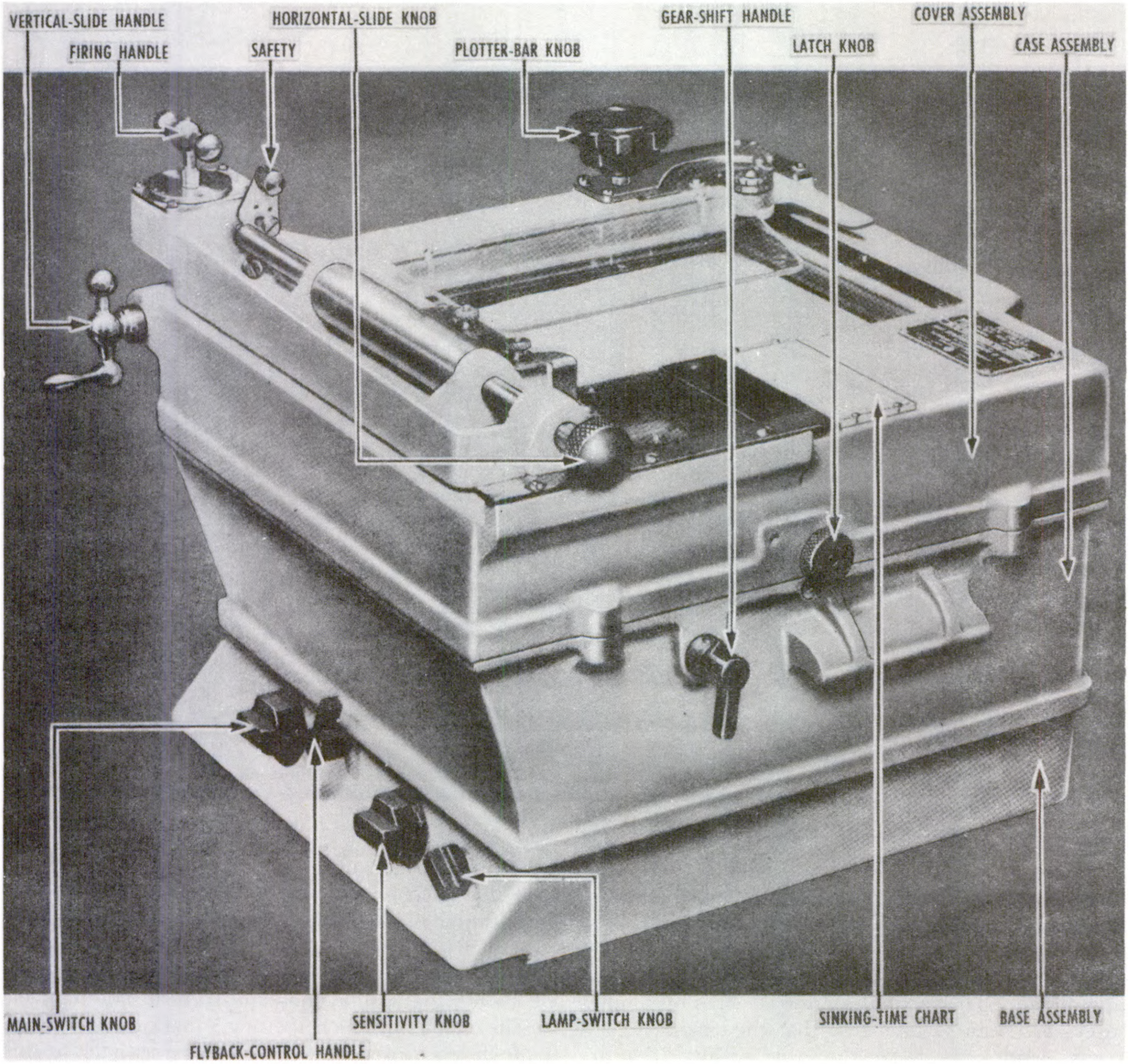


FIGURE 28C2.—Tactical range recorder.

2. *Firing-lag difference scale (upper right scale inscribed 0, 6, 12).* The time of flight for hedgehogs is set on this scale to remove the *Tf* effect of the bow firing-lag scale setting when firing stern-dropped charges. This setting, of course, is determined from the range tables for the missiles concerned.

3. *Projector-to-stern scale (inscribed* PROJ. TO STERN*).* On this scale is set the distance in feet from the sonar transducer to the depth-charge racks on the stern (*i. e.,* the parallax base line P1). It is obtained from ship's plans and is constant for each ship.

4. *Backing-plate scale (located beneath R_E scale and inscribed* FEET*).* The distance in feet from the sonar transducer to the depth-charge racks on the stern is set on this scale to remove the effect of the projector-to-stern scale setting when firing throwing weapons.

5. *Effective-range scale (inscribed R_E).* On this scale is set the range of the hedgehog missiles *Re* as determined by the conditions existing at the time.

6. *Zero-zero scale (to the left of R_E scale and inscribed 0, 6, 12).* This scale is used for alignment purposes.

In addition to the more or less permanent scales above, there are also two scales whose settings may have to be changed as an attack progresses. They are—

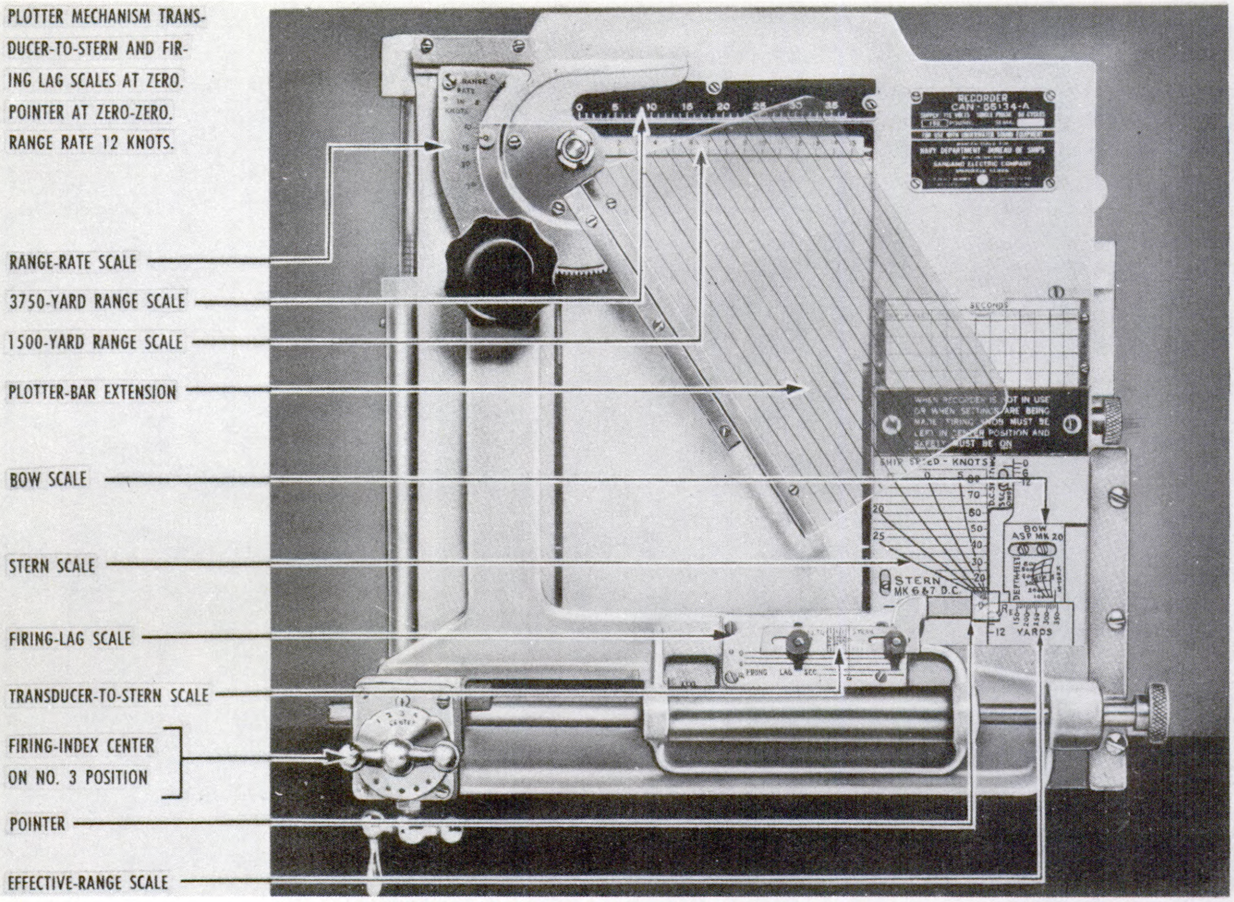


FIGURE 28C3.—Front view of the tactical range recorder.

7. *Stern-data scale* (*inscribed* STERN). On this are set own ship's speed of attack (*So*) and the sinking time (*Td*) (labeled D. C. SETTING SECONDS) for depth charges. The ship's speed is obtained from the pitometer log, and the sinking time depends on the target depth. The sinking rate for all types of depth charges has been so tabulated that the sinking time to any depth may be determined readily. Depth charges are set to explode at a pattern in depth as well as in range and deflection, in order to enclose a volume of water which will include the submarine. The measured or assumed depth which is the mean of the pattern is used in making this setting.

8. *Bow-data scale* (*inscribed* BOW). On this are set own ship's speed of attack (*So*) and the sinking time (*Td*) (labeled SECONDS) for hedgehogs. As in a depth-charge attack, the ship's speed is obtained from the pitometer log and the sinking time is calculated from the known sinking rate of the hedgehogs to the measured or assumed depth.

The settings on the stern and bow data scale are made by means of the *data-scale indicator*. This indicator is a lucite arm which is attached to the horizontal slide bar; its index, as illustrated in figure 28C3 is a "dot." This index or "dot" is positioned over the intersection of the proper data lines (*So* and *Td*) on either the stern-data scale (for a D/C attack) or bow-data scale (for a fixed H/H attack) by means of the horizontal slide knob and vertical slide handle.

The manner in which a setting is made on any of the more-or-less permanent scales can be seen in figure 28C3. Briefly, a value is set on the—

1. Bow firing-lag scale, by moving the projector-to-stern scale vertically.
2. Firing-lag difference scale, by moving the stern-data scale vertically.
3. Projector-to-stern scale, by moving it horizontally.
4. Backing-plate scale by moving the effective-range scale (R_E) horizontally.
5. Effective-range scale by moving the bow-data scale horizontally.

These settings on the more or less permanent scales (listed in 1–5 above) all serve to position either the stern and bow data scales or the data-scale indicator index with respect to the origin of the chart paper. Consequently, they either increase or decrease the time remaining until firing should occur. This effect can be understood more readily if it is realized that the data-scale indicator, projector-to-stern scale, bow firing-lag scale, and plotter bar are all mounted on the same frame and hence all move together whenever the horizontal slide knob or the vertical slide handle is turned.

For example, consider the effects of the bow firing-lag scale and firing-lag difference scale settings on firing time. From figure 28C3 it can be seen that, once the data-scale indicator index is positioned at a certain point, an increase in the bow firing-lag scale setting (a change in $Tf+Tg$ from 9 to 12 seconds, for example) will move the data-scale indicator index down (as viewed in the illustration). Hence it will be necessary to drive the index back up to its original position by turning the vertical slide handle. Moving the index back up, in turn, will result in the plotter bar and its extension also moving up, closer to the traces, with the result that firing time for H/H will occur sooner.

Part of this motion of the plotter bar (the part corresponding to the Tf setting for H/H) will result in an incorrect firing time when firing depth charges; consequently, we must counteract for this effect by setting the Tf of H/H on the firing-lag difference scale. This is done by physically moving the stern-data scale down until the index at the upper right corner of the scale is opposite the appropriate value of Tf on the firing-lag difference scale. This downward motion of the stern-data scale will necessitate downward motion of the data-scale indicator index which, in turn, will result in the plotter bar's being moved far enough away from the traces to assure firing of depth charges at the proper time.

Similarly, it could be shown that (1) an increased projector-to-stern scale setting would delay firing of depth charges a desired amount; (2) a corresponding increase in the backing-plate scale setting would compensate for this delay when firing fixed hedgehogs; and (3) a decreased effective-range scale setting would result in an earlier firing time.

Because the tactical range recorder takes into consideration only the range aspects of the problem, the conning officer must rely on other sources for assistance in determining the proper course and speed to use to attain a firing position. Assistance from CIC, various "thumb rules" determined from experience, and a "seaman's eye" are the general practice.

When a stern-dropped (depth-charge) attack is to be conducted, appropriate values of own ship's attack speed (So) and sinking time (Td) are entered on the stern-data scale by turning the horizontal slide knob and vertical slide handle until the data-scale indicator index is properly positioned. As the range to the target closes, the traces on the plotter chart will move toward the left. When the leading edge of the trace is under the firing line, it is time to fire the charge. There is a barrage firing knob on the horizontal slide bar which is used to fire a pattern in range. This knob is kept in center position *3* during the approach. When the range closes to about 500 yards, it is moved to position *1*, which moves the plotter bar a fixed amount to the right, thus making the firing time for the first charge of the pattern earlier than the center. When the firing line is over the leading edge of the traces, the first charge is fired and the knob shifted to position *2*, which moves the firing line to the left. These steps are then repeated until all five charges have been fired.

A fixed throwing-weapons (hedgehog) attack is conducted in a similar manner, except that the bow-data scale is used and the barrage firing knob is left on position *3* (the position which corresponds to a Tud of zero).

28C3. Attack plotter

The attack plotter (AP) is an electronic instrument which displays on the face of a cathode-ray tube a geographical picture of own-ship and target motion. See figure 28C4. The own-ship indication is a single bright dot which moves across the scope according to the true course and speed of own ship as received automatically from the gyrocompass and pitometer log. There are N–S and E–W controls on the front of the instrument for making the initial setting of own ship's position. The operator positions the ship at the edge of the scope, so that at the commencement of an attack the entire scope is available for plotting the encounter. If the operator positioned own ship at the center of the scope, he would risk having insufficient space on the

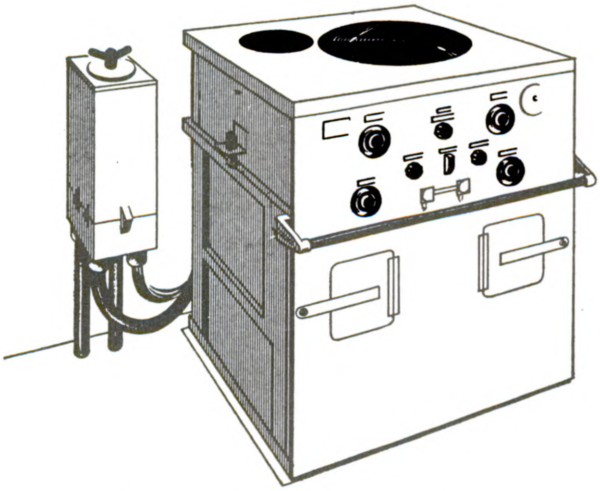


FIGURE 28C4.—The attack plotter.

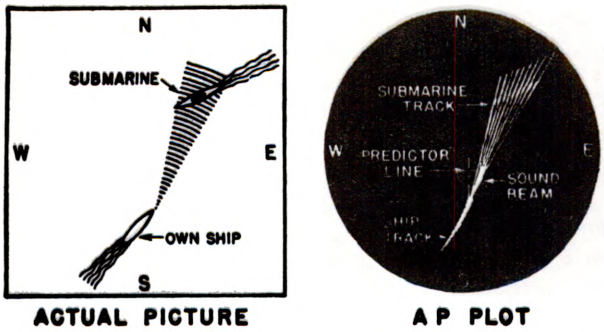


Figure 28C5.—Attack-plotter picture *versus* true picture.

scope to plot the attack. In a prolonged attack, therefore, the operator might have to reposition ship and target just at weapons-launching time, thus reducing the accuracy of the attack.

The target position, which is also indicated on the scope as a bright spot, is controlled by the audio section of the scanning sonar. As the sound beam is projected through water, a faint line is visible on the scope, originating at own ship and proceeding in the direction the audio section is trained. If the beam strikes a target and returns an echo, a pip brightens on the scope, showing the target's position in relation to own ship. The picture thus presented assists the operator in determining the proper course to steer to reach firing position.

Another important feature of the AP is the *predictor line*. This is a bright line which momentarily flashes on the face of the scope immediately after own ship's spot and just before the sound sweep starts. The direction and length of this line are controlled by the operator. Thus the length of the line can be adjusted to the effective range of projector-type weapons, and the line can be trained to the bearing along which the ship must proceed to intercept the target. The bearing of the predictor line can be transmitted automatically as a course order to the steersman, who keeps the ship's head corrected as necessary for the approach and attack.

Refer to figure 28C5 for comparison of a true picture *versus* an attack-plotter picture.

Both the tactical range recorder and the attack plotter are A/S fire control instruments of long standing. In many vessels they remain primary instruments for controlling the attack. In highly specialized A/S ships, they are generally installed as secondary fire control instruments.

The recorder supplies range rate and weapons-launching time. It is also a valuable aid for classifying echoes—submarine, probable submarine, or non-submarine. A trained operator can interpret traces and determine target aspect: direct bow, bow, beam, quarter, or stern. Notice the five standard target aspects in figure 28C6. Target aspect literally means the aspect the submarine presents to the attacking ship. *Direct bow* means the sub is approaching head-on; *stern* means the sub is moving directly away from the ship. The aspects may be further modified by such expressions as *slight quarter* or *deep quarter*. With target aspect and direction of bearing drift, it is possible for the officer to determine approximate target angle.

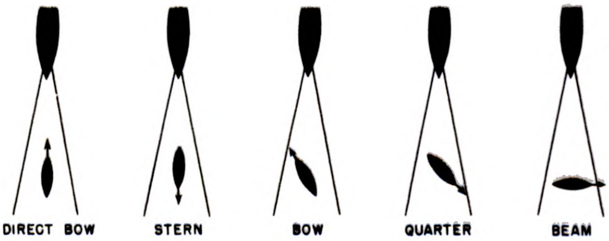


Figure 28C6.—Target aspects.

The AP can be used to determine target course, speed, and angle. When equipped with a predictor line, it provides firing time and course to steer for a fixed projector-type weapon attack.

D. OKA-1 Sonar-Resolving Equipment

28D1. Introduction

The OKA-1 sonar-resolving equipment consists of the following three major units:

1. Range recorder.
2. Range computer.
3. Horizontal range recorder.

Either the TRR or the OKA-1 Range Recorder can be used with the QHB scanning sonar equipment, but both cannot be used simultaneously.

28D2. OKA-1 range recorder

Figure 28D1 illustrates the OKA-1 range recorder. This piece of equipment performs the following functions:

1. It records the value of sonar range *Rq*.
2. It provides for the measurement of sonar range rate.
3. It may be used to control the keying circuit of the QHBa scanning sonar equipment.

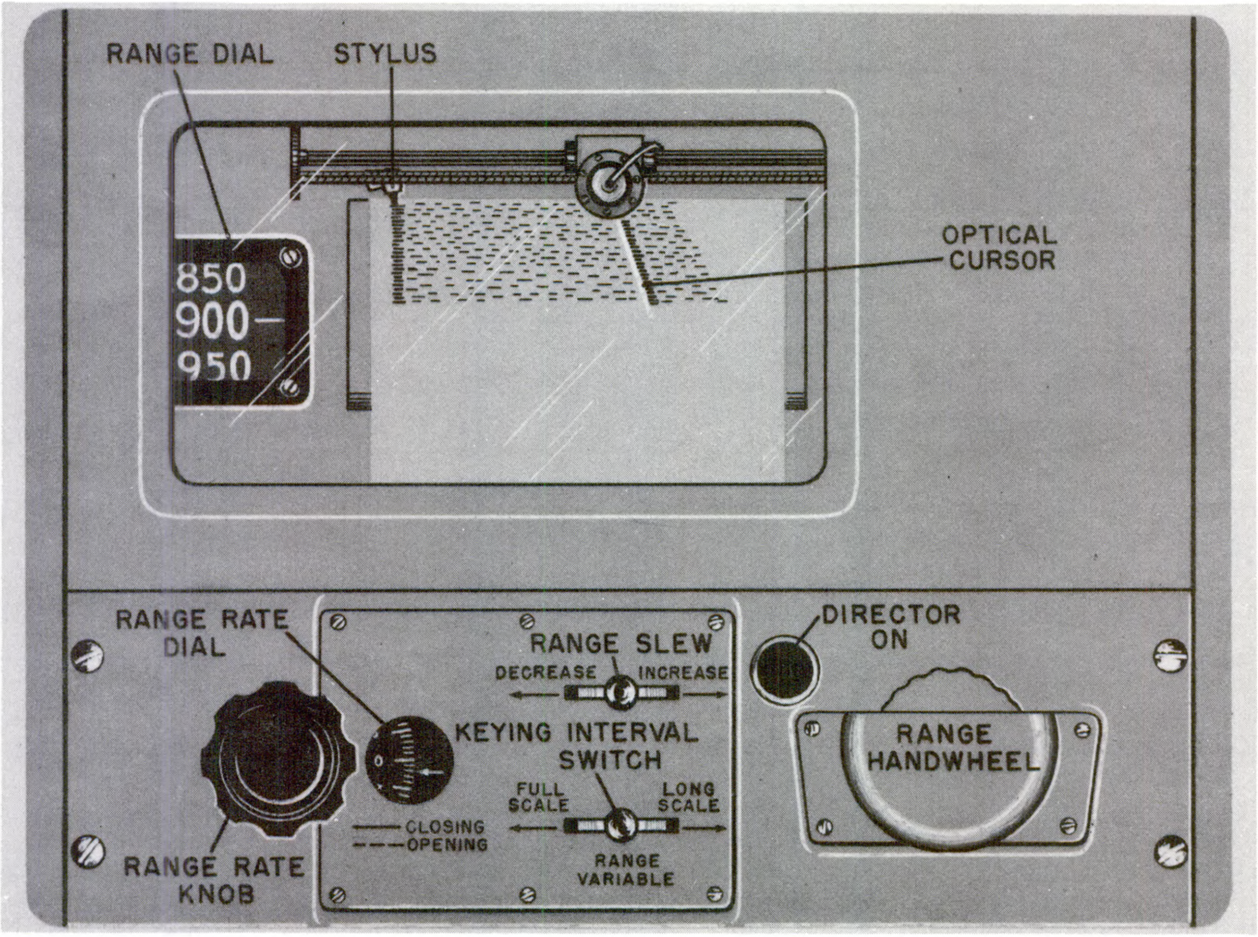


FIGURE 28D1.—OKA-1 range recorder.

The recorder mechanism (as shown in fig. 28D1) is made up of a strip chart device employing moist, chemically sensitized paper which moves slowly at a constant speed in a direction perpendicular to the path of a reciprocating stylus. During its recording motion this stylus traverses the chart from left to right at a speed proportional to half the speed of sound in sea water, and is rapidly returned to the left after each stroke.

The stylus starts its recording motion at the instant the transmitted pulse leaves the transducer. The audio signal received by the QHBa equipment is applied to the stylus, causing a passage of current through the paper when an echo is received and resulting in a visible mark. Therefore, since the stylus started its motion at the instant the pulse was transmitted and moves at a rate proportional to half the speed of sound, the distance from the starting point to the mark is a measure of the sonar range to the target.

Determination of the sonar range to the target is accomplished by an optical cursor (light beam) which projects a cursor image on the recorder chart. This image is moved across the chart to the position of the last target mark by a synchro system which provides sonar range Rq to the OKA-1 range computer and, in addition, indicates the value of this range on a dial on the recorder. The optical cursor is rotatable, so that it may be lined up with a series of range marks as the paper moves down the recorder at a constant speed which represents time. The slope of the optical cursor, when properly lined up, is therefore a measure of the rate of change of sonar range.

The *controls* for operating the OKA-1 range recorder are located on both the top panel and the front panel of the instrument. Those on the top panel are shown in figure 28D1 and are described in the paragraphs that follow.

1. *Range slew, range handwheel, range dial.* The range slew and range handwheel move the optical cursor (light beam) across the scale horizontally.

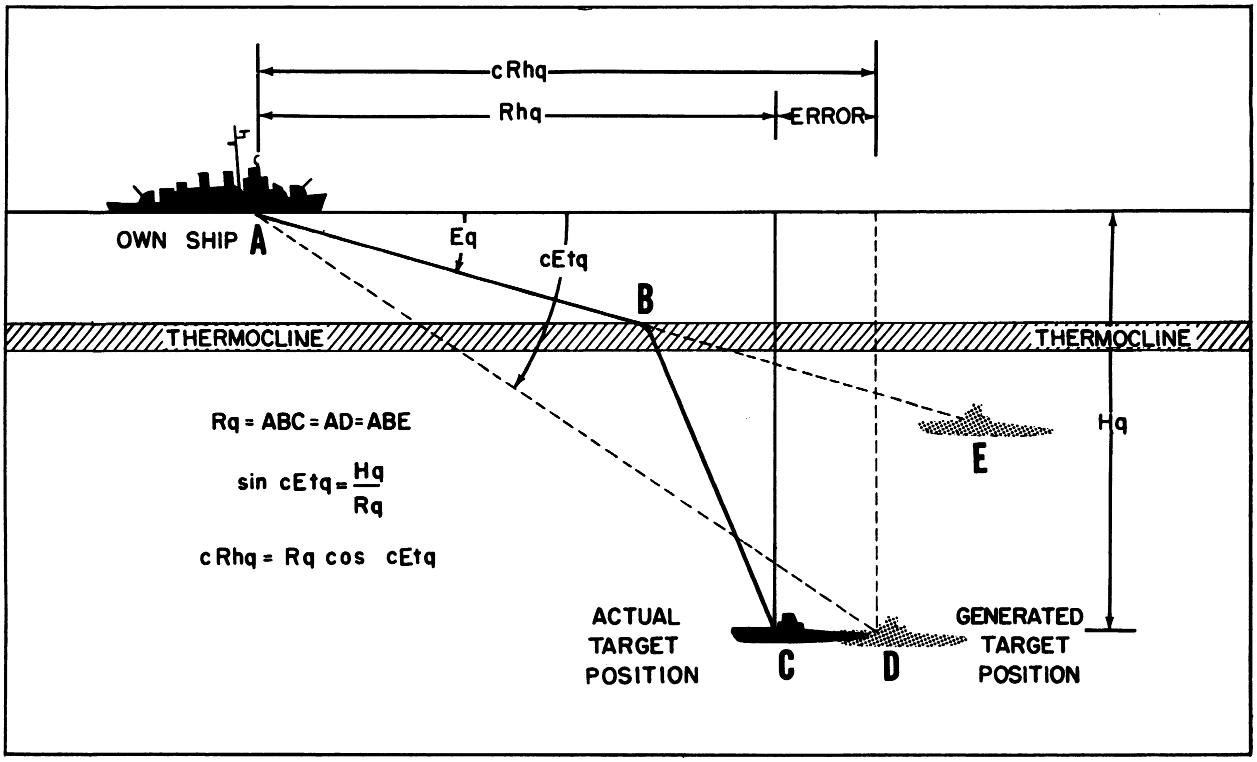


FIGURE 28D2.—Generation of horizontal sonar range by OKA–1 range computer.

The slew is used to position the cursor initially on a target; the handwheel, to provide the attack director with rate control corrections. Any horizontal motion of the cursor is recorded on the range dial located at the left of the recorder chart. Whenever the cursor is properly positioned over the target, this dial indicates the instantaneous value of sonar range *Rq*.

2. *Range-rate knob and dial.* These are shown at the lower left corner of figure 28D1. The range-rate knob controls the slope of the optical cursor as well as the operation of the cursor-positioning synchro system mentioned above. When the knob is turned so that the cursor assumes a vertical position, the reading on the range-rate dial will be zero and the synchro system will not move the cursor. This is the normal condition when slewing to a new target.

However, once a target is acquired and the optical cursor is aligned with a series of range marks which collectively have a definite slope, the range-rate dial will indicate a value of range rate corresponding to that slope. Moreover, the value of range rate will cause the synchro system to position the cursor continuously over the range marks. As long as the actual range rate of the target does not change, the target will be tracked automatically and correct values of *Rq* will be transmitted to the OKA-1 range computer.

3. *Keying-interval switch.* This switch performs a function similar to that of the keying selector switch of the QHBa indicator control. It controls the range scale of the recorder chart and hence the keying interval or time between successive sweeps. The recorder has two electrical contacts called *flybacks,* one fixed and one variable in position. The fixed flyback is located at the extreme top right of the chart; the variable one is attached to the pivot point of the optical cursor. When the stylus, moving to the right, strikes one of these flybacks, it is returned rapidly to the left.

The keying-interval switch utilizes both flybacks in its control of the range scale and keying interval. This switch has three positions: FULL SCALE, RANGE VARIABLE, and LONG SCALE. When it is positioned to LONG SCALE (when it is desired to obtain echoes from different targets within maximum range, for example), the width of the recorder chart represents 3750 yards, and the stylus bypasses the variable flyback and moves at a slow speed all the way over to the right edge of the chart before being restored to the left by the fixed flyback. When the keying-interval switch is set to FULL SCALE (when it is desired to search for echoes beyond the range of a target being tracked, for example), the stylus covers the entire width of the recorder chart in a similar manner.

However, in this case, the scale of the chart (and hence the speed of the stylus) is dependent upon the

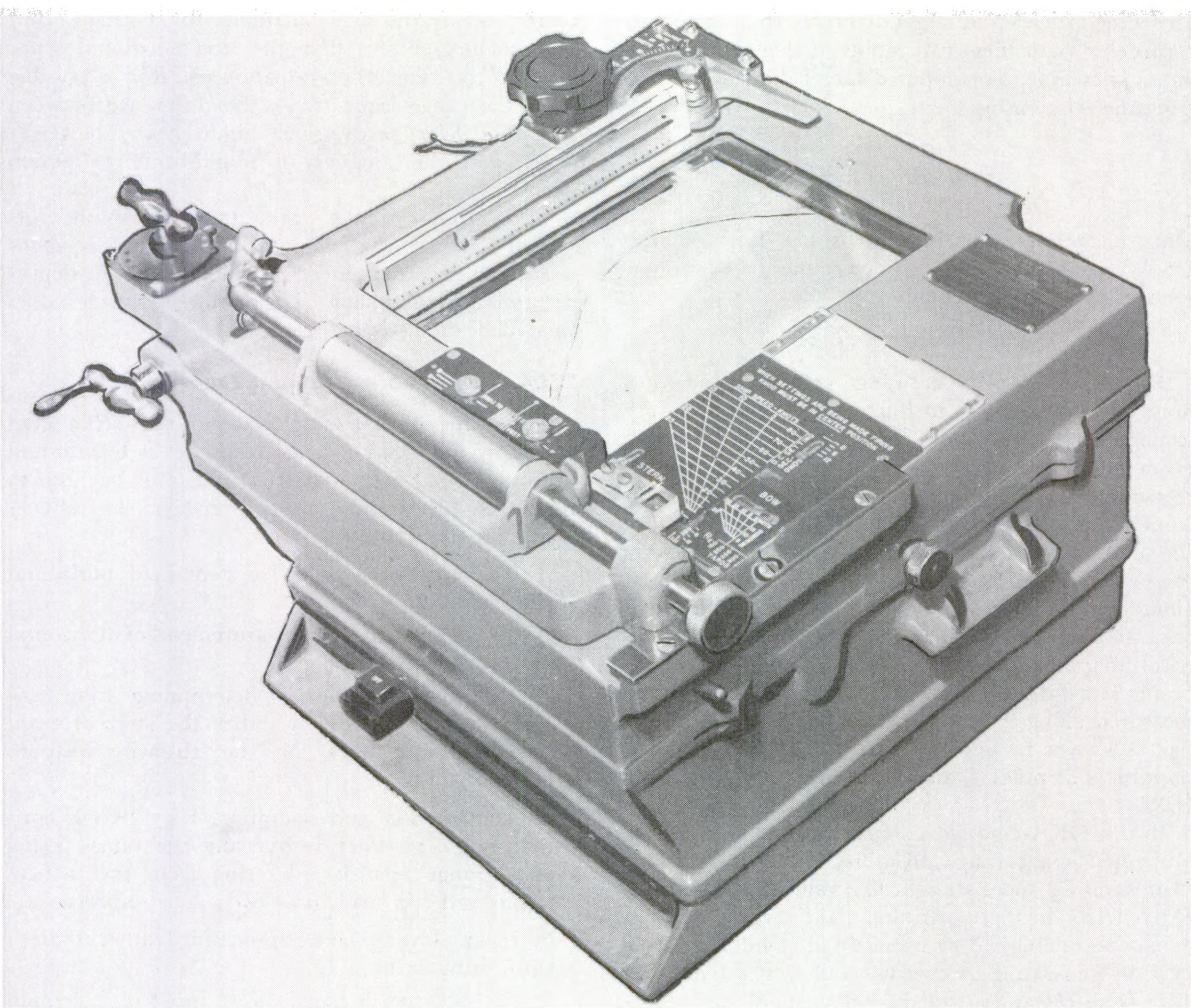


FIGURE 28D3.—Horizontal range recorder.

position of the optical cursor. If the cursor is to the right of approximately the 1450-yard position, the stylus will move at a slow speed over the 3750-yard chart. If the cursor range is less than approximately 1450 yards, on the other hand, the scale of the chart will be 1500 yards, and the stylus will move at a fast speed. Finally, when the keying-interval switch is positioned to RANGE VARIABLE (the normal operating position), the range scale and stylus speed again will be dependent upon the position of the optical cursor (as in FULL SCALE). In this case, however, the variable flyback will control the stylus in such a manner that the stylus will move to a point 200 yards beyond the actual cursor range before being restored to the left.

There are various other controls and indicators on the front panel of the OKA-1 range recorder. However, most of these are self-explanatory (*i. e.*, CHART LIGHTING, STYLUS SENSITIVITY, *etc.*) and hence will not be described here. One of the controls, an attack-director ON-OFF switch, is used in aided tracking.

Within the recorder case itself there is an adjustment which provides for variations of sound velocity in sea water V (and hence for variations in stylus speed) as a function of water temperature.

28D3. OKA-1 range computer

The primary functions of this unit of the OKA-1 sonar-resolving equipment are to compute the following quantities:

1. Generated horizontal sonar range $cRhq$.
2. Stylus speed for the depth recorder.

To acomplish the first of these functions, the OKA-1 range computer receives inputs of sonar range Rq from the OKA-1 range recorder (as described in the preceding article) and target depth Hq from the depth recorder. With these two inputs, it then generates a value known as the computed target depression $cEtq$ from the relationship:

$$\sin cEtq = \frac{Hq.}{Rq}$$

Once $cEtq$ is known through its sine function, the OKA-1 range computer can determine the horizontal sonar range from the equation:

$$cRhq = Rq \cos cEtq.$$

To understand why the range computer generates horizontal sonar range in this manner, it is necessary to understand more about the refraction of the sound beam mentioned in article 28A3. If there were no refraction of the sound beam, the sonar range Rq would also be the slant range to the target; that is, the sound beam would follow a straight line connecting own ship and target, and Rq would be measured along this line. However, if the sound beam were refracted at some point in its travel by a steep temperature gradient or *thermocline,* Rq no longer would be the straight-line range to the target, but would be measured along the refracted sound beam. This effect is shown in figure 28D2. The target's actual position is at point *C* and Rq is measured along line *ABC*.

If the OKA-1 range computer were to compute horizontal sonar range $cRhq$ from inputs of target depression Eq and a straight-line value of sonar range Rq ($=ABE$ in the illustration), the target's position would be established erroneously at point *E*. However, by generating its own value of target depression $cEtq$ from Hq and a straight-line value of Rq ($=AD$ in fig. 28D2), the range computer effectively establishes the target's position as point *D,* which is at the correct depth and at a horizontal sonar range $cRhq$ only slightly greater than the true horizontal sonar range Rhq. This approximation of $cRhq$ is possible since the range error (*i. e.,* the difference between $cRhq$ and Rhq) progressively diminishes as the target closes and the amount of sound-beam refraction decreases.

The OKA-1 range computer accomplishes its second function, the computation of stylus speed for the depth recorder, in conjunction with the depth-determining equipment. The manner in which it does this will be discussed in section E.

28D4. OKA-1 horizontal range recorder

The value of horizontal sonar range $cRhq$ generated by the OKA-1 range computer is transmitted not only to a range and depth indicator but also to the OKA-1 horizontal range recorder (fig. 28D3) whose functions are—

1. To record the value of generated horizontal sonar range $cRhq$.
2. To provide for the measurement of horizontal sonar range rate.
3. To provide a means of determining firing time (*i. e.,* when $Tud=0$) for either the stern-dropped (depth-charge) attack or the throwing-weapons (hedgehog) attack.

In construction and operation, the OKA-1 horizontal range recorder is basically the same as the tactical range recorder, differing from the tactical range recorder in really only two major respects:

1. It employs a nonreciprocating rather than a reciprocating stylus.
2. Its operation is based on an input of generated horizontal sonar range $cRhq$ rather than on an input of the audio response from the QHBa equipment.

E. Depth-Determining Sonar Equipment

28E1. Introduction

No one particular type of depth-determining equipment will be described in this article. The various types employed at the present time (the QDA being an example) all have similar functions when used with the OKA-1 sonar-resolving equipment. That is, they—

1. Measure and transmit to other units the value of sonar depression Eq.
2. Record and transmit to other units the value of target depth Hq.

28E2. Description

Most of the depth-determining equipments now employed in the fleet use the same basic principle for computing target depth. This principle involves measuring the depression angle of the sound beam to the target, then resolving the speed of sound in water along that sound beam into its component in a vertical plane. Then this component of the velocity of sound in water is used to control the stylus speed of a recorder, with the excursion of the stylus starting at the instant the sound is transmitted into the water and the stylus marking a recorder paper when the echo is received.

The recorder paper moves from one roller onto another, so that there will always be a new measurement of depth whenever an echo is received from the target on the depth-determining sonar equipment. The depth-determining sonar uses either a tiltable transducer or a fixed transducer with a scanning receiving beam for measurement of the depression angle of the sound beam.

If there were no refraction of sound in water, the sound beam would follow the straight line connecting own ship and target. However, as pointed out previously, temperature, pressure, and salinity differences will cause variations in water density which, in turn, will result in refraction of the sound beam. The effects of salinity and pressure variations are minor and will be neglected in this discussion. The effect of temperature variations, on the other hand, is appreciable and will be discussed in more detail.

The temperature varies rather irregularly, due to currents and sea conditions. Generally speaking, however, it remains relatively constant down to a certain depth (known as the *layer depth*), then becomes rapidly cooler in a region known as the *thermocline,* and finally is relatively constant (but cooler) again until another thermocline is reached.

The effect of thermoclines (*i. e.,* regions of steep temperature gradients) upon sound beams is twofold. In the first place, because of the change in water density at the thermocline, sound beams other than those normal to the thermocline will be refracted downward (toward the normal) as they enter the cooler, more dense water.

Because of these effects, the depth of the thermocline below the surface of the water (the layer depth) must be measured every few hours if accurate determination of target depth *Hq* is going to be possible. This measurement is accomplished by use of an instrument known as the ***bathythermograph*** (B/T).

The B/T, which contains pressure- and temperature-measuring devices, is lowered over the side of a surface ship on the end of a long wire. During its descent it records pressure (which is a measure of depth) versus temperature on a slide which can be placed in a viewer and read when the B/T is recovered.

Figure 28E1 shows a typical B/T slide presentation. The layer depth, it can be seen, is readily ascertained. Moreover, from the values of temperature indicated on the B/T slide, it also is possible, by using appropriate tables, to determine the velocity of sound at the surface (V) and the decrease in velocity at the thermocline (ΔV).

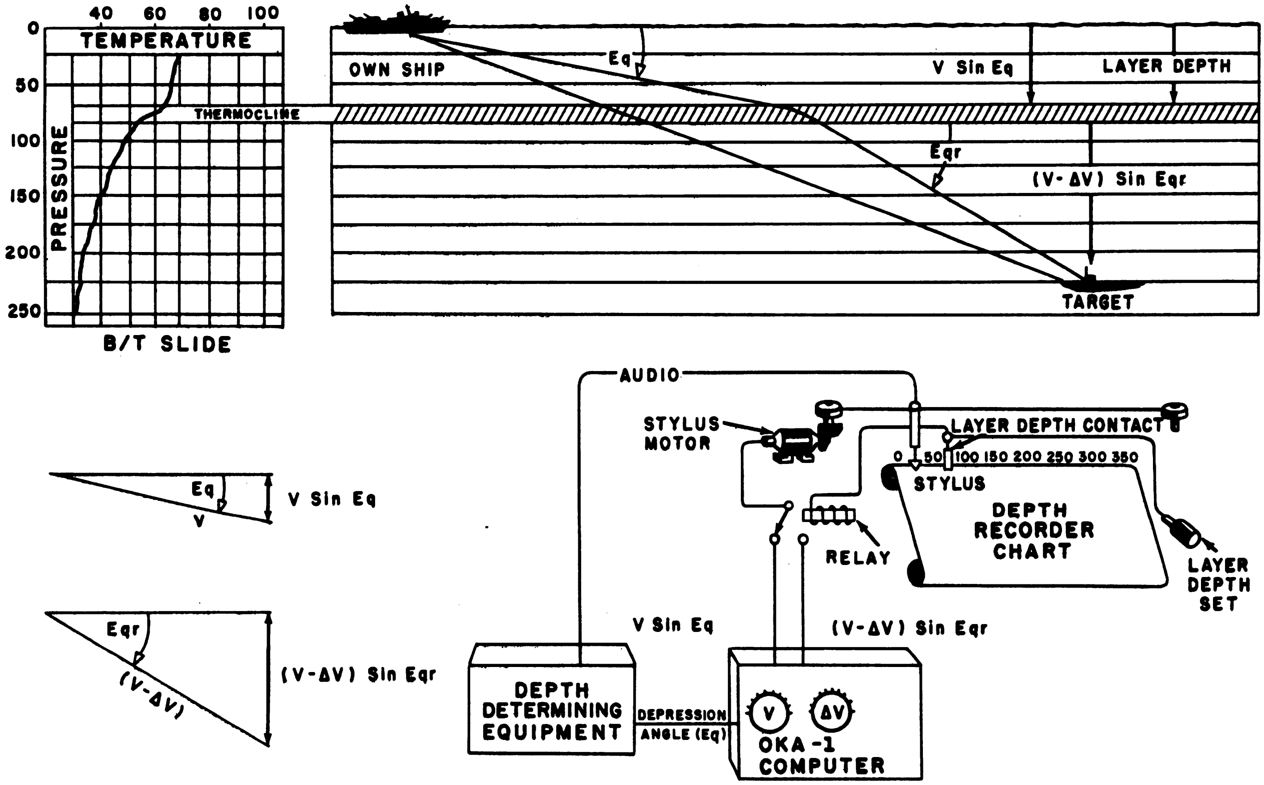


FIGURE 28E1.—Computation of stylus speed for depth recorder.

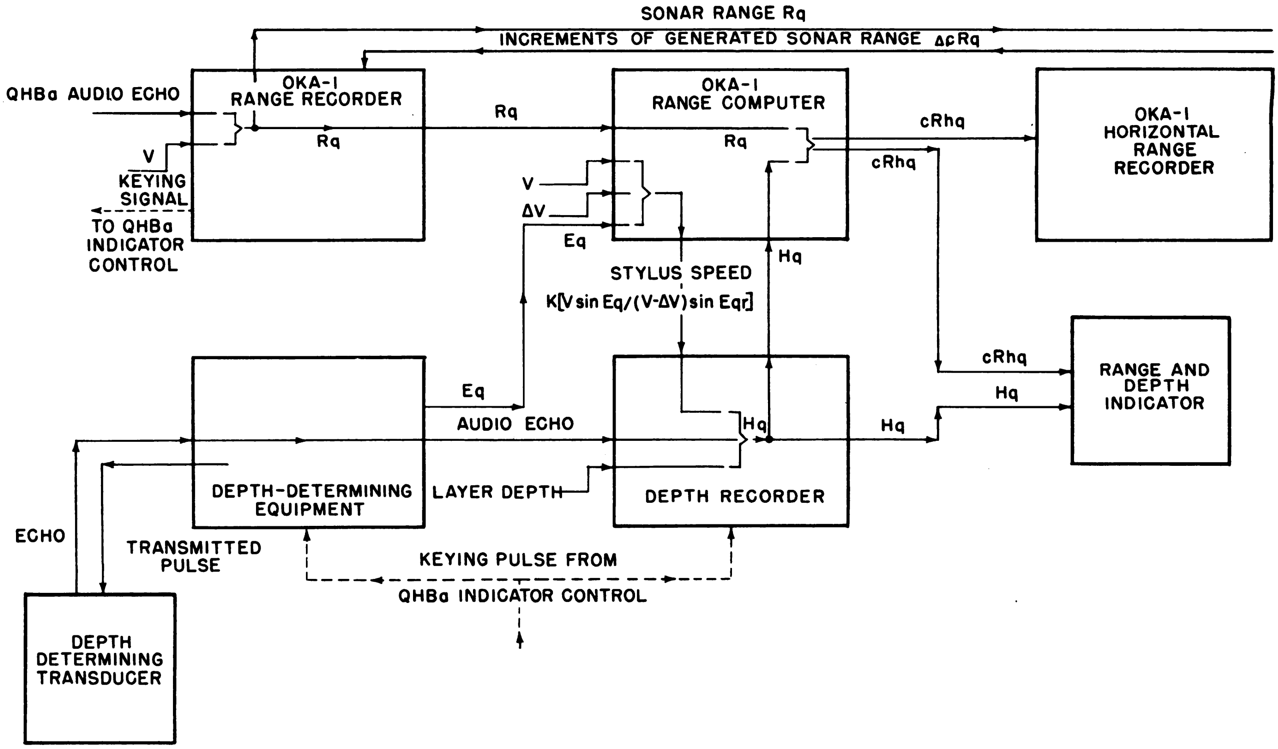


FIGURE 28E2.—Operation of OKA-1 sonar-resolving and depth-determining equipments.

One of the functions of the OKA-1 range computer, as pointed out in article 28D3, is to compute stylus speed for the depth recorder. From figure 28E1 it should be evident that two different stylus speeds are required: one, the starting speed, proportional to the vertical component of the velocity of sound at the surface, V sin Eq; the other proportional to the vertical component of the velocity of sound after layer depth is reached $(V-\Delta V)$ sin Eqr. The OKA-1 range computer receives sonar depression Eq automatically from the depth-determining equipment and inputs of V and ΔV by hand as shown in figure 28E1. Then, using these three values (V, ΔV, and Eq), it computes the sonar depression after refraction Eqr from an equation known as Snell's Law:

$$\frac{V-\Delta V}{V}=\frac{\cos Eqr}{\cos Eq}.$$

Once Eqr is known, the stylus speeds proportional to V sin Eq and $(V-\Delta V)$ sin Eqr can readily be generated.

The change from one stylus speed to another in the depth recorder is accomplished, as shown in figure 28E1, by positioning a contact maker at a point representing layer depth. The moving stylus, upon striking this contact maker, will trip a relay in the stylus-speed circuit which will change the speed from one proportional to V sin Eq to one proportional to $(V-\Delta V)$ sin Eqr. The audio response from the depth-determining equipment is fed through the stylus in a way that marks the sensitized paper whenever a target echo is received. Basically, the operation of the depth recorder is the same as that of the OKA-1 range recorder except for the two speeds involved in stylus excursion.

28E3. Summary of the OKA-1 and depth-determining system

Figure 28E2 illustrates, in simplified schematic form, the operation of the various units of the OKA-1 sonar-resolving and depth-determining equipments.

Chapter 29

MISSILE CONTROL AND GUIDANCE SYSTEMS

A. Introduction

29A1. General

The principal parts of a guided missile, aside from its airframe, are its propulsion system, its war head and fuze, and the systems that control and guide it during flight. Chapter 11 of this text includes a discussion of guided missiles in general, and goes into some detail about missile propulsion systems, war heads, and fuzes. The present chapter deals with missile control and guidance systems.

A guided missile is capable of controlling its flight path in accordance with information received from an outside source. Depending on the guidance system used, this information may be pre-set in the missile before launching, or it may be received in flight. Information received in flight is usually in the form of electromagnetic radiation: radio waves, radiant heat, or light. The missile may receive this information from the target, or from guidance devices near the launcher. A single missile may use a combination of two or more forms of guidance.

The control systems compare the present position and attitude of the missile with the flight path determined by the guidance system, and effect any necessary changes in missile trajectory.

B. Control Systems

29B1. Introduction

A guidance system is a robot device capable of directing the flight of a missile in response to intelligence set into it, or to commands originating from outside the missile. The functions of such a system are to stabilize the missile axes with respect to a desired flight path and to orient the missile with respect to a target. Figure 29B5 shows the three mutually perpendicular axes (yaw, pitch, and roll) which the guidance system must be capable of positioning correctly to accomplish the above functions.

A missile in flight is subject to angular rotation about the yaw, pitch, and roll axes. Figures 29B1 and 29B2 show a missile with a yaw error and a pitch error respectively. If the missile is to remain stabilized with respect to the flight path, devices within the missile must be capable of detecting, measuring, and correcting yaw and pitch errors in order to keep the nose of the missile always pointed along the flight path. In addition, for the missile control vanes to function properly, the missile must not be permitted to roll about its longitudinal axis. Control of the angular motion of the missile about the yaw, pitch, and roll axes is called *attitude control*. Each guidance system must contain an attitude control system.

In addition to angular rotation, a missile is capable of translation from the correct flight path. Figures 29B3 and 29B4 show a missile with a lateral error and a vertical error respectively. In addition, a missile may develop a range error along the desired flight path. Control of the translation of the missile with respect to its flight path is called *path control*. Each guidance system must contain a path control system, the function

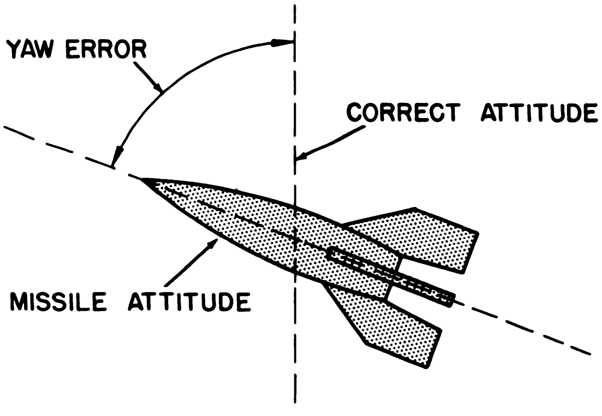


FIGURE 29B1.—Attitude error in yaw (top view).

of which is lateral control, vertical control, and range control.

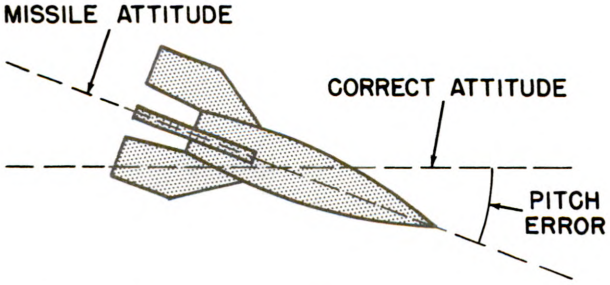


Figure 29B2.—Attitude error in pitch (side view).

29B2. Attitude control system

Control of the angular rotation of the missile about each of its three axes is accomplished by the attitude control system, all units of which are located within the missile. In addition, this system provides a reference common to both the missile and its control unit(s) It enables the missile to distinguish up from down and right from left, and to determine when it is rolling. For example, assume a missile is not roll-stabilized, and for some reason has rolled upside down. If a signal sent from the control unit ordered the missile to turn right, it would turn left, since it has no way of knowing that it is on its back.

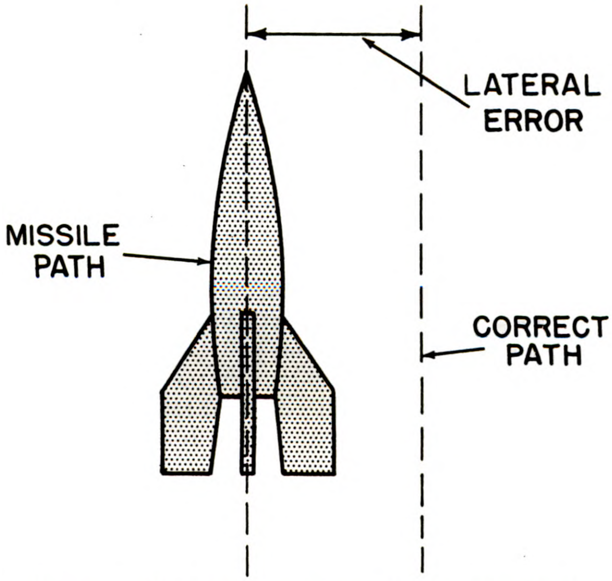


Figure 29B3.—Lateral path control error (top view).

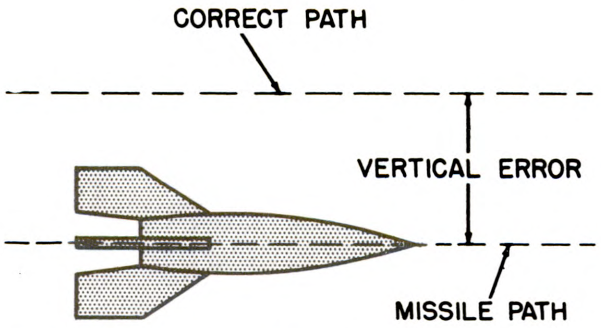


Figure 29B4.—Vertical path control error (side view).

In general, the following components are used to achieve attitude control in a guided missile: a reference, a detector, a controller, and control devices to turn the missile about its yaw, pitch, and roll axes.

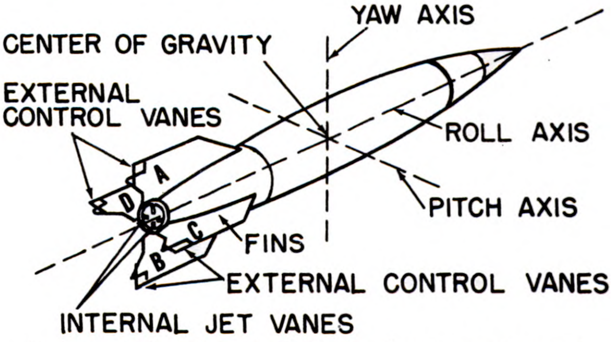


Figure 29B5.—Guided missile showing external control vanes.

Figure 29B6 shows how these components might be utilized in the pitch attitude control system of a missile. Similar components would be utilized in the same missile for the yaw and roll attitude control systems.

1. A *reference* is some device which will give the missile a known line in space from which to measure

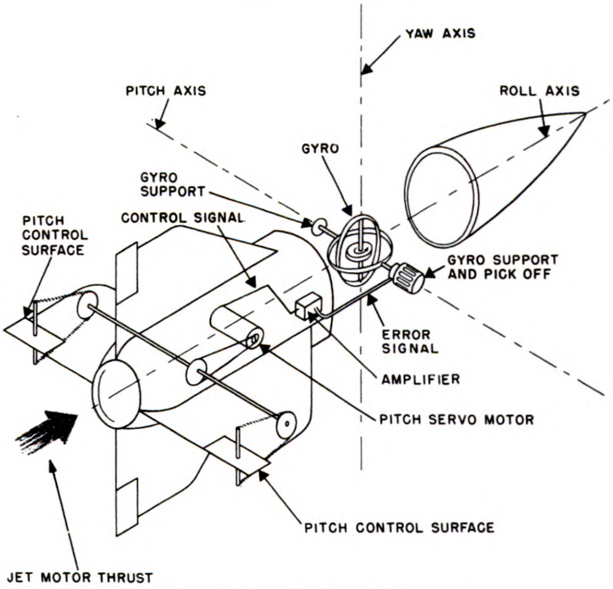


Figure 29B6.—Pitch control system.

attitude errors. An example of a reference device is the gyroscope, whose attitude is fixed with respect to space. The orientation of the gyro spin axes with respect to the missile would depend upon the operational and design requirements of the missile. For example, in a surface-to-surface missile designed to maintain level flight with respect to the earth, the gyro spin axis would be set in the missile to coincide with the true vertical with respect to the earth. Then any angular movement of the missile in yaw and pitch will be in a plane parallel to the earth's surface and in a plane perpendicular to the earth's surface, respectively. If the gyro is to be employed for very long periods of time or while the missile is moving over an appreciable part of the earth's surface, a primary reference such as the magnetic compass or average position of a pendulum must be used to keep the gyro spin axis precessed to the true vertical.

For an air-to-air missile designed to keep its nose always pointed toward the target, it might be desirable to keep the gyro spin axis always perpendicular to the missile flight path. In this application, an additional device, such as a radar, would be required to determine the flight path and continuously keep the gyro spin axis precessed to the correct position.

If the gyro is to be employed as the reference device, one gyro can serve as a reference for any two of the three types of attitude control (yaw, pitch, and roll). Normally, two gyroscopes are used, one for the yaw and pitch control systems, and one for the roll control system.

2. A *detector* is a device that will measure any attitude error that develops throughout the flight of the missile. If, for example, the gryoscope is used as a reference, a simple potentiometer can be used for the detector. If the potentiometer resistor is attached to the missile casing and the potentiometer wiper or arm is attached to a gyro gimbal shaft, any movement of the missile (and hence the resistor) will vary the position of the wiper on the resistor and cause the detector to measure a voltage proportional to the deviation of the missile from its correct attitude. This voltage, which will be very small, is used as the error signal.

3. A *controller* is a power device that is controlled by the small error signal. Since the signal detected is usually very small, it must be amplified before it can be used to drive servo motors to which are connected elements that cause motion of the missile about the various axes (yaw, pitch, roll). The controller usually consists of an amplifier and the necessary servo motors connected with it.

4. Various types of *control devices* positioned by the controller servo motor cause angular movement of the missile about the yaw, pitch, and roll axes.

a. *External control vanes or movable fins* mounted externally on the missile, and similar to the rudders or elevators on a conventional aircraft, can be moved in the stream of air passing over the body. They will cause a greater force of air pressure to be built up on one side of the vane or fin than on the other, causing the missile to shift angularly in any direction desired. For both yaw and pitch, control vanes within one plane can be moved simultaneously in the same direction. For example, in figure 29B5 we can achieve yaw control by moving vanes A and B in the same direction, and the missile will change course accordingly. To achieve pitch control, vanes C and D are moved simultaneously in the same direction. For roll control, it is necessary to develop a torque which will turn the missile about its longitudinal axis. To accomplish this, opposite control surfaces, such as A and B, are moved in opposite directions. The difference in pressure built up on opposite sides of these control vanes will tend to roll the missile about its longitudinal axis, thereby providing a method of roll control. These control vanes and fins, however, can operate only when the missile is traveling at velocities high enough to give an effective air flow past the vanes or fins. In addition, they will be of little use in missiles flying above the earth's atmosphere where there is relatively little air.

b. *Jet vanes* placed in the stream of hot exhaust gases from the motor can be used to control the missile's attitude until the missile attains sufficient velocity for the external control vanes or movable fins to become effective, or during the time the missile is above the earth's atmosphere. The operation is similar to that of the external vanes and fins. Control is achieved by the proper positioning of the jet vanes in the high-velocity exhaust gases, just as the control vanes are moved in the air stream, in order to produce missile motion in the desired direction. Jet vanes, however, have a limited life due to the extreme temperatures they must withstand. The normal life of the jet vanes in German V–2 rocket was approximately 60 seconds.

c. A *gimballed motor* is another device which may be used. The missile motor is mounted in a system of gimbals similar to the gimbal system used for a gyroscope. By causing the output of the controller servo motors to rotate the gimbals with respect to one another, the direction of the thrust of the motor can be changed, resulting in a change of heading of the missile. This device will operate at any missile velocity, and whether the missile is in or out of the atmosphere.

d. *Auxiliary jets* may also be used to change the direction of motion of a missile. They can be mounted around the periphery of the missile at its center of gravity to cause lateral or vertical displacement of the missile, or they can be mounted parallel to the main propulsion system so that the missile's over-all line of thrust can be changed, thus creating a turning movement.

When the reference, detector, controller, and control devices are assembled and mounted in a missile, they provide the missile with the means for maintaining stable flight on the desired flight heading. Referring to figure 29B6, assure our missile on a given heading develops a pitch error. Movement of the missile in pitch causes rotation of the missile casing with respect to the gyro reference, thereby causing displacement of the detector resistor with respect to the detector arm or wiper. This movement, noted by the potentiometer detector, is measured as an error signal or voltage (proportional to the movement in pitch) and sent to the controller. Within the controller, the error signal is amplified and applied to the pitch servo motor. The pitch servo motor then moves the pitch control vanes to cause the missile to correct the pitch error. When the missile is once again at the correct attitude in pitch, the error signal has decreased to zero, and the control vanes have returned to their neutral position.

29B3. Path control system

The path control system normally acts through the attitude control system. It must provide the orders or navigational information to the attitude control system to cause the missile to take the flight path for which the missile was designed. As explained above, the path control system must operate to keep the missile on its designed flight path to the target by providing a means for lateral, vertical, and range control.

Path control can be achieved by making the missile believe it has an attitude error. For example, if the missile is displaced laterally from its path, it may be made to move to the proper path by making it think it has a yaw attitude error. Correcting this false error, the missile will change its heading until it reaches the proper position, at which time another false error is sent to the yaw control system to bring the missile back to its proper attitude. Vertical control can be accomplished in a similar manner by making the missile think it has an error in pitch. One method of controlling range is by utilizing an order from the path control system to cut off the fuel supply to the motor of the missile when the desired range is attained.

In order to provide the attitude control system with the proper orders or navigational information to enable the missile to keep on the desired flight path, each path control system must consist of the following components: tracker, computers, directing devices.

1. *Tracker.* Before any intelligent commands can be sent to the missile, it is necessary to know the location of the missile with respect to the target. If the missile is not on the desired path to the target, the tracker will observe an error. The tracker may be in the missile, on the ground, or in the air. Tracking is accomplished optically, by radio, by radar, or by some means which utilizes a distinguishing feature of the target or missile against its background. For long range all-weather tracking, radar has been found most satisfactory.

2. *Computers.* The computers calculate directing signals for the missile by use of information from the tracker. The directing signals will tell the missile how much to move the control surfaces to properly position itself on the desired flight path. Computing may be accomplished on the ground, in the missile, or in both places. A missile may use more than one computing element. For example, an altimeter may be used to maintain the missile at the correct altitude, and an air log computer may be used to initiate a signal to cut off the fuel to the propulsion system when a pre-set range has been recorded.

3. *Directing devices.* Directing is the process of sending the computed order to the missile. This can be accomplished by sending radio or radar signals to a receiver in the missile when directing is to be accomplished from the ground. When directing is to be accomplished within the missile, the computed order is sent from one sub-component to another by electric, pneumatic, or hydraulic signals.

The directing signal can now be introduced into the controllers of the attitude control system either to correct the missile's lateral or vertical deviation from the desired flight path or to cause the missile to change course or altitude. In addition, the directing signal can be used to vary the propulsive force of the missile and hence the range.

C. Basic Guidance Systems

29C1. General

As has been previously stated, every guidance system consists of an attitude control system and some sort of a path control system. The name of the path control system depends upon the unique manner in which path control is accomplished. Since nearly all missiles use the same type of attitude control system, it is common practice to refer to the guidance system by the name of the path control system. The following is a list of the eight basic guidance systems:

Pre-set
Terrestrial reference
Inertial
Celestial navigation
Radio navigation
Command
Beam rider
Homing

The pre-set, terrestrial reference, inertial, and celestial navigation systems are often referred to as self-contained guidance systems. In these systems, the missile is made to fly a predetermined path calculated prior to launching. Devices wholly within the missile cause the missile to remain on the correct flight path to the target. Such systems provide an excellent means for guiding surface-to-surface missiles. The principal advantage is that there are no existing countermeasures. The principal disadvantage is that accuracy is generally poor due to instrument errors; consequently these systems, unless combined with another system, are limited to area targets.

The radio navigation, command, beam rider, and homing systems all depend on signals from an external source to keep the missile continuously on the correct flight path. The principal advantage of these systems is greater accuracy than the self-contained systems. The principal disadvantage is high susceptibility to countermeasures.

29C2. Pre-set guidance system

A pre-set guidance system is one in which a predetermined path is set into the missile prior to launching, and cannot be adjusted after launching. The principal device used in the pre-set missile is a *programmer*. The programmer is a set of switches and an electric or other type of time motor which operates to close the switches at the proper time after launching, to cause components in the missile to perform certain functions as the missile proceeds along its flight path.

The Germans used the pre-set system in the V–2 rocket employed against England during World War II. Prior to launching, the V–2 was oriented with respect to the target. Four seconds after launching, the programmer caused a false pitch signal to be sent to the pitch attitude control system, causing the missile to pitch to a predetermined angle toward the target. The missile remained at this attitude until the propulsion system accelerated it to a velocity sufficient to carry the missile to the target. At this point, the programmer caused a signal to be sent to a fuel cut-off valve, shutting off the fuel to the rocket motor. The V–2 then followed a free-flight ballistic trajectory to the target similar to the trajectory followed by a projectile fired from a conventional gun. The guidance range obtainable with the current pre-set system is about 200 miles.

29C3. Terrestrial reference guidance system

A terrestrial reference guidance system is one in which the predetermined path can be adjusted after launching by devices within the missile which react to some phenomenon of the earth. One of the best illustrations of this system is the German buzz bomb or V–1. The missile course was monitored by a magnetic compass placed in the nose. If the missile turned to the right or left, the compass created an error signal which directed the servo to bring it back on course by correct movement of the control vanes. The V–1 also utilized another phenomenon of the earth—atmospheric air density. By use of a barometer (altimeter), it compared the air density against a pre-set air density. If a difference existed, the device initiated the required error signal to move the missile to the correct altitude. Before firing, the bearing of the target was set into the missile by orienting the compass; the range was set on an air log similar to a speedometer connected to a small propeller; and the altimeter or air-density measuring device was set to maintain the proper altitude.

Control of the V-1 employed the earth's magnetic field and the atmospheric air density. Although not practical at present because of the lack of exact knowledge, other references which might be used in the future are cosmic rays, gravitational field, electric field, and configuration of the earth's surface. As with the pre-set system, the guidance range currently obtainable with the terrestrial reference system is about 200 miles.

29C4. Inertial guidance system

An inertial guidance system is a system designed for a predetermined path in which the path of the missile is adjusted after launching by devices wholly within the missile, making use of the principle of Newton's second law of motion ($F=Ma$), and independent of any outside information. In the simplest system, the missile contains devices called accelerometers to detect and measure accelerations in two directions. Acceleration errors detected and measured by the accelerometers are doubly integrated to obtain the distances the missile is off its predetermined flight path. A missile would require one accelerometer for vertical path control and another for lateral path control. If, at launching, the missile is pointed at the target, the missile must move so as to keep the right-left distance and up-down distance zero. Meanwhile a range device measures the distance traveled by the missile along its flight path. When a pre-set range is reached, the missile dives into the target. Based on present-day techniques in design and construction, it is expected that a guidance range of 12,500 miles can be achieved by a missile employing the inertial guidance system.

29C5. Celestial navigation guidance system

A celestial navigation guidance system is a system designed for a predetermined path in which the path of the missile is adjusted by the use of continuous celestial navigation. The system is based on the known apparent positions of celestial bodies with respect to points on the surface of the earth at a given time. Such a system is highly desirable for long-range missiles since its accuracy is independent of range. In its application to guided missiles, we must provide in the missile a means of doing the same thing a navigator does when he takes celestial sights. The missile must be provided with a horizontal or vertical reference to the earth, automatic star-tracking telescopes to determine star-elevation angles with respect to the reference, a time base, and navigational star tables mechanically or electrically recorded. A computer continuously compares star observations with the time base and navigational tables to determine the missile's present position. The present position is then compared with the predetermined position, and the proper signals computed to steer the missile correctly toward the target. As with the inertial guidance system, it is expected that the guidance range of a missile employing this guidance system will be 12,500 miles.

29C6. Radio navigation guidance system

A radio navigation guidance system is a system designed for a predetermined path in which the path of the missile is adjusted by devices in the missile that are controlled by external radio signals. The simplest method is one in which the missile is able, by means of a directional antenna, to maintain predetermined bearings with respect to two radio transmitters. The most highly developed method is the hyperbolic system. It is based on the measurement by a receiver in the missile of the time delay of signals from two synchronized transmitters in a known location. If the time difference is kept constant, a hyperbolic course will result.

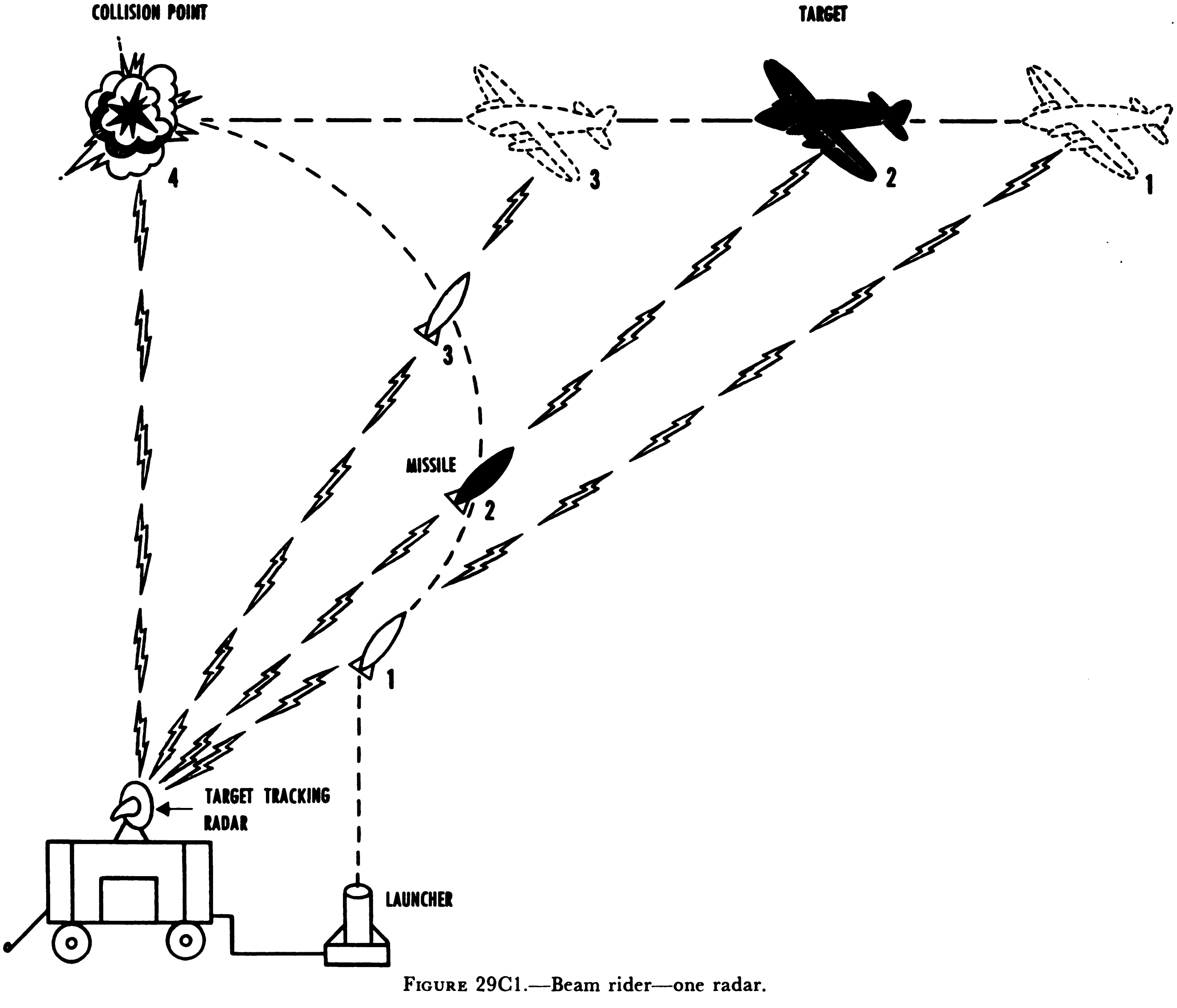


Figure 29C1.—Beam rider—one radar.

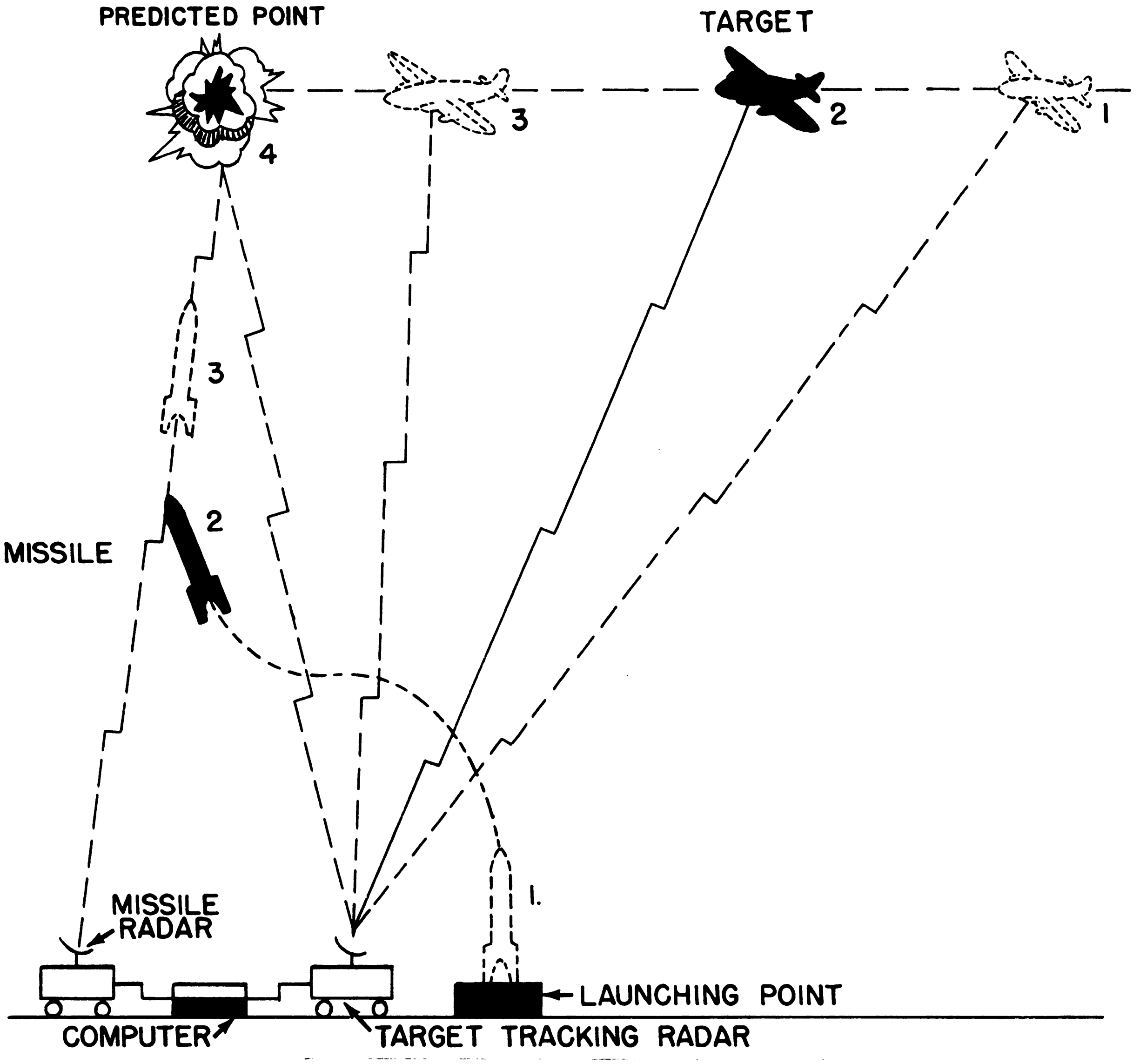


FIGURE 29C2.—Beam rider—two radars.

Altitude is generally determined by an altimeter. Range may be determined by the addition of a third transmitting station. LORAN and SHORAN are examples of radio navigation systems. The guidance range expected with this system is about 500 miles.

29C7. Command guidance system

A command guidance system is one in which the path of the missile can be changed after launching by directing signals from some agency outside the missile. The control station obtains information of the relative positions of the target and the missile so as to direct the missile to intercept or attack the target along some trajectory.

Many variations of this method may be used to guide a missile. One of the simplest methods is the system used to guide a drone plane in to a target. A human operator observes the drone and target and sends commands to the drone over a radio command link. These commands cause the servos of the attitude control system to properly position the drone elevators and rudders to execute the desired maneuver. In a more complex, advanced surface-to-air system, the human operator is replaced by two radars and a computer. One radar is used to track the target and the other to track the missile. The computer continuously compares the present position of the missile with that of the target and determines new missile flight paths based

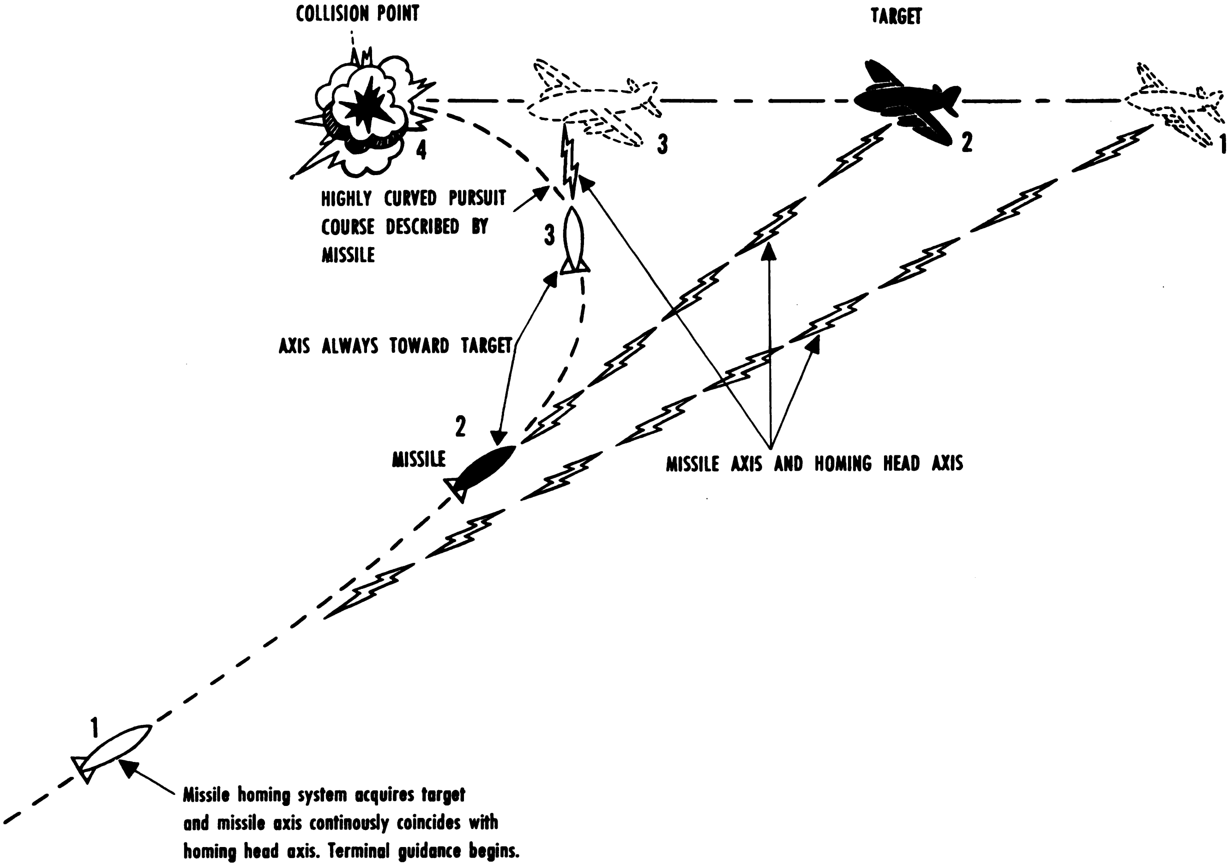

COLLISION POINT
TARGET
4
3
2
1
HIGHLY CURVED PURSUIT COURSE DESCRIBED BY MISSILE
3
AXIS ALWAYS TOWARD TARGET
2
MISSILE
MISSILE AXIS AND HOMING HEAD AXIS
1
Missile homing system acquires target and missile axis continously coincides with homing head axis. Terminal guidance begins.

FIGURE 29C3.—Homing guidance—pursuit flight path.

on errors present in missile-target relative positions. Radio commands which cause the missile to fly the new flight path are sent to the missile by the missile-tracking radar beam. Guidance ranges possible with this type of system will depend upon the ability of the radio or radar transmitters to transmit an effective signal to the missile. With current equipment, guidance ranges possible for a missile-employing command guidance are about 75 to 100 miles.

29C8. Beam-rider guidance system

A beam-rider guidance system is one in which the direction of the missile can be changed after launching by devices within the missile, which cause it to seek out the center of the beam. Radars produce the most promising types of beams. In addition to radar, other phenomena such as light and heat might be used for this purpose.

In one type of radar beam-rider system, the target-tracking radar continuously tracks the target. The missile, launched into the beam, continuously seeks out the center of the radar beam until it intercepts the target. In such a system, the missile will fly a changing line-of-sight course to the target, especially when the target is flying a crossing course as illustrated in figure 29C1. Because the radar beam must continuously be directed at and moved with the target, such a flight path possesses the disadvantage of requiring extremely high traverse accelerations of the missile.

The disadvantage of the one-radar beam-rider system is overcome by another system employing two radars and a computer. The target-tracking radar feeds target position data into the computer, which calculates a predicted position of the target based on target data and missile data. A second, or missile, radar is pointed toward the predicted target position, and the missile follows the center of this radar beam, which also supplies missile data to the computer. If the target does not maneuver, and if the calculation of the predicted point is correct, the missile radar beam does not need to be moved from the predicted point; then the missile will fly a straight-line course toward collision with the target as indicated in figure 29C2. If the target maneuvers, or if the computation of the predicted point is in error, the predicted point, and hence the direction of the missile

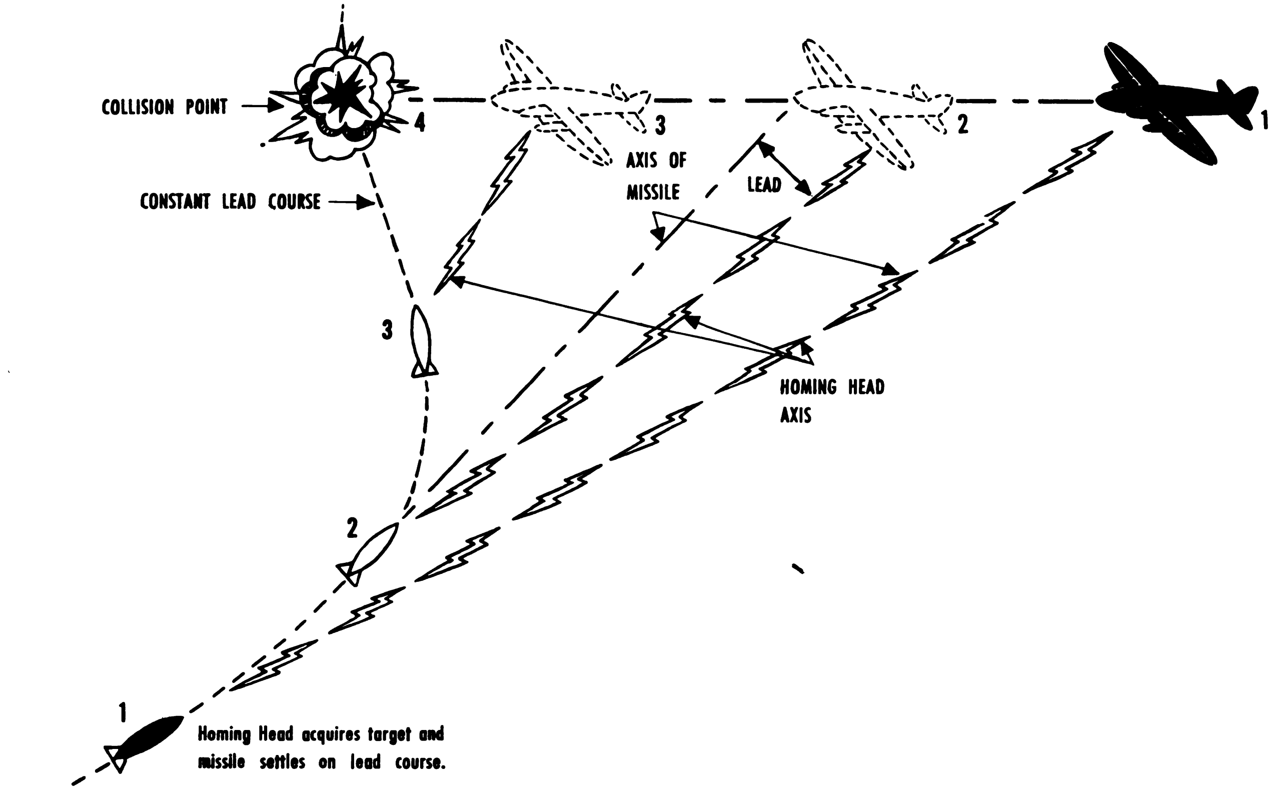


Figure 29C4.—Homing guidance—lead flight path.

radar beam, will change. Such changes may be expected to be relatively small and to require lower accelerations of the missile than with the type of system employing only one radar beam. The disadvantage of the second system described is the additional complicated equipment involved.

The beam-rider guidance system is especially adaptable for use against incoming air targets, and thus can be expected to be used for AA defense of ships at sea and of cities on land. A number of missiles can be launched into the beam at once, and if the targets aren't too widely separated, the beam can be shifted to a new target with missiles already in the beam. Accuracy decreases with an increase in range, however, due to the spreading of the radar beam at the longer ranges. As with the command guidance system, possible guidance ranges with present-day radar beam-rider systems are from 75 to 100 miles.

29C9. Homing guidance system

A homing guidance system is one in which the direction of the missile can be changed by a device within the missile which reacts to some distinguishing characteristic of the target. Basically, a homing system consists of a seeker or scanner in the missile which automatically keeps "locked on" or pointed at some special characteristic of the target. The seeker must also send target data to a missile computer which computes signals to cause the attitude control system to keep the missile headed on the correct flight path to intercept the target. The important target characteristics which provide a means for the missile to pick out or keep "locked on" the target are: light emissions, radio emissions, radar reflectivity, infrared (heat) emissions, sound emissions, capacitve features, and magnetic features. To date, the best means of target detection has been through infrared (heat) emissions and radar reflections. These systems are sufficiently accurate that collision may be expected.

In homing systems, the missile must carry all of the equipment and, because of the weight factor, will be limited to short-range operation. Since accuracy of this system increases as the missile approaches the source of energy emitted by the target, a homing system is ideal for terminal guidance. For example, a surface-to-air missile might employ beam-rider guidance to within a few miles of the target and infrared homing guidance to impact with the target. In this manner, the inaccuracy of the beam rider at the outer limits of its radar range might be overcome. At present, the missile must be within 30 miles of the target for successful radar homing and within 5 miles of the target for successful infrared homing.

The homing missile may be designed to follow a highly curved flight path (known as the pursuit flight path) resulting from the missile's longitudinal axis always being pointed toward the target, as illustrated in figure 29C3. This flight path requires extremely high accelerations from the missile, particularly just before it intercepts the target; consequently, the pursuit flight path is most effective against slow-moving or fixed targets. For fast-moving targets, a lead-type flight path, as illustrated in figure 29C4, might be employed. Whereas lower accelerations are required by this flight path, the missile must carry more complicated guidance equipment.

In the pursuit-type flight path, the missile seeker mounted along the longitudinal axis of the missile "locks on" some distinguishing feature of the target. If the missile's longitudinal axis is not pointed toward the target continuously, error signals are produced by the seeker, which cause the attitude control system to change the missile's heading. A lead-type flight path will result if the seeker is offset at some angle from the missile's longitudinal axis. When the seeker is "locked on" a target, the nose of the missile will be pointed ahead of the target by the amount of the offset angle.

Homing systems are generally classified as active, semiactive, or passive systems. In active homing systems, the missile carries the equipment required to illuminate the target, and the system is independent of an external agent. In a semiactive homing system, some agency outside the missile, such as a ground unit or aircraft, illuminates the target. Thus a ground unit or aircraft would keep a radar beam on target and the missile radar receiver would receive the target echoes. In passive homing, the target supplies the necessary illumination upon which the missile will home. A missile designed to home on the infrared or heat radiations from a jet aircraft, or a ship at sea, is a passive homer.

29C10. Combination guidance systems

Many of the foregoing guidance systems may be combined to utilize the advantages of each system. For example, a surface-to-air missile might utilize pre-set guidance during the launching phase to orient the missile in a radar beam, beam-rider guidance during the midcourse guidance phase, and homing guidance during the terminal phase when the beam-rider accuracy decreases. A surface-to-surface missile might utilize pre-set guidance during the launching phase to orient the missile with the target, celestial navigation during the midcourse long-range guidance phase, and homing guidance to enable the missile to pinpoint the target.

Chapter 30

ORGANIZATION AND COMMUNICATIONS

A. Battle Organization

30A1. Introduction

In order that a ship's armament and fire control can be used to perform its primary mission, that of destroying the enemy, an efficient organization and means of communication between the various parts of that organization must be provided. In practically all ships, and particularly the larger ones, the fire control stations are widely separated; yet each is dependent upon the others for collection of information, computation of firing data, and transmission of orders. Therefore, one of the most important phases of shipboard gunnery is to organize effectively the ship's personnel and matériel and to ensure rapid and accurate transmission of orders and of fire control data.

30A2. Battle bill

In all United States Navy combatant ships, a battle bill is drawn up and officially promulgated for the guidance and coordination of all subdivisions of the ship's organization during battle. The battle organization as set forth in this bill does not in all respects parallel the administrative organization of the ship, although there are standard and fixed relationships between the two types of organization.

Figure 30A1 shows a part of a battle bill in schematic diagram. Only the fire control subdivision is fully outlined here. Each main subdivision of the organization is administered separately and functions under the Commanding Officer through its own chain of command. It must be remembered, however, that the major subdivisions are closely related and that a thorough understanding of all of them is essential to the coordination of battle activities.

One of the first responsibilities of an officer reporting on board a ship is to study the battle bill carefully. The full text of this bill will list the personnel in each of the various battle stations and will list the communications channels available to each station. When studying such a bill under peacetime or drill conditions, one should not be overly eager to find flaws therein. Many seeming inconsistencies in thoroughly tested battle bills have quite adequate explanations in exigencies of wartime cruising or battle conditions. Aboard each ship, efforts are continually made to arrive at the most efficient battle organization.

30A3. Organization similarities

The organization shown in figure 30A1 varies from ship to ship, and even to a limited extent among ships of the same class. However, every effort is made to standardize the organization for all types of ships, insofar as such standardization can be achieved with the existing differences in ship construction, armament, and available communications circuits. To the extent that standardization is possible, it enables all officers and men to be generally familiar with the organization of all ships. Thus an interchange of personnel does not present a major training problem, and new hands may be worked with ease into the existing organization aboard any ship.

Thus, although the organization for various ships may differ in detail, the plan shown in figure 30A1 covers the essential features common to all combatant types. Battleships and cruisers which have single-purpose main batteries will all have organizations resembling closely the one shown in the illustration, although the exact number of parts into which each battery is divided will depend upon the equipment on the individual ship. Antiaircraft cruisers and smaller ships which have dual-purpose main batteries have organizations similar to the illustrated plan with the main battery omitted.

30A4. Chain of command

The various subdivisions and stations shown in figure 30A1 are connected by lines which show both the *chain of command* and the *flow of communications.* Opposed arrows on the lines indicate the transmission of data and the resulting orders for utilizing those data.

All lines emanate from Command, because the Captain from his battle station exercises control over all ship activities. In particular he has responsibility for the supervision of his ship's course and speed, the use of armament, the preservation of watertight integrity, the procedures used in case of casualties to personnel and matériel, and the receipt and dissemination of information. The task of coordinating the many activities so as to obtain a smoothly functioning organization is a tremendous one; it is obviously necessary that some agency be available to assist the Captain in performing his many functions.

30A5. Combat Information Center

The function of Combat Information Center (CIC) is to assist Command in planning the correct course of action, and to assist Command and the main subordinate control officers in the execution of that plan. CIC is, briefly, an agency for the collection, evaluation, and distribution of combat information, and for facilitating the use of that information. CIC assists the Captain especially by filtering and evaluating nearly all incoming information. The Captain is given required facts as he needs them and thus is left free to concentrate on those decisions which he must make. The Captain may delegate secondary decisions and control duties to CIC as the case may require.

CIC, in exercising its function as an information center, coordinates the activities of the ship's search radar, lookouts, and other means of obtaining external information. With all such information readily available to it, CIC is of considerable direct assistance to the fire control party. To facilitate the receipt by the fire control organization of information originating in CIC, the Gunnery Department usually keeps one or more officers, designated as *Gunnery Liaison Officers,* stationed in CIC and in constant communication with the principal fire control officers. Through the channels thus provided, CIC is able to perform, when requested or in accordance with standard doctrine, any of several functions in connection with the control of weapons. It may:

1. Designate or suggest suitable targets.
2. Coach the fire control directors on to targets.

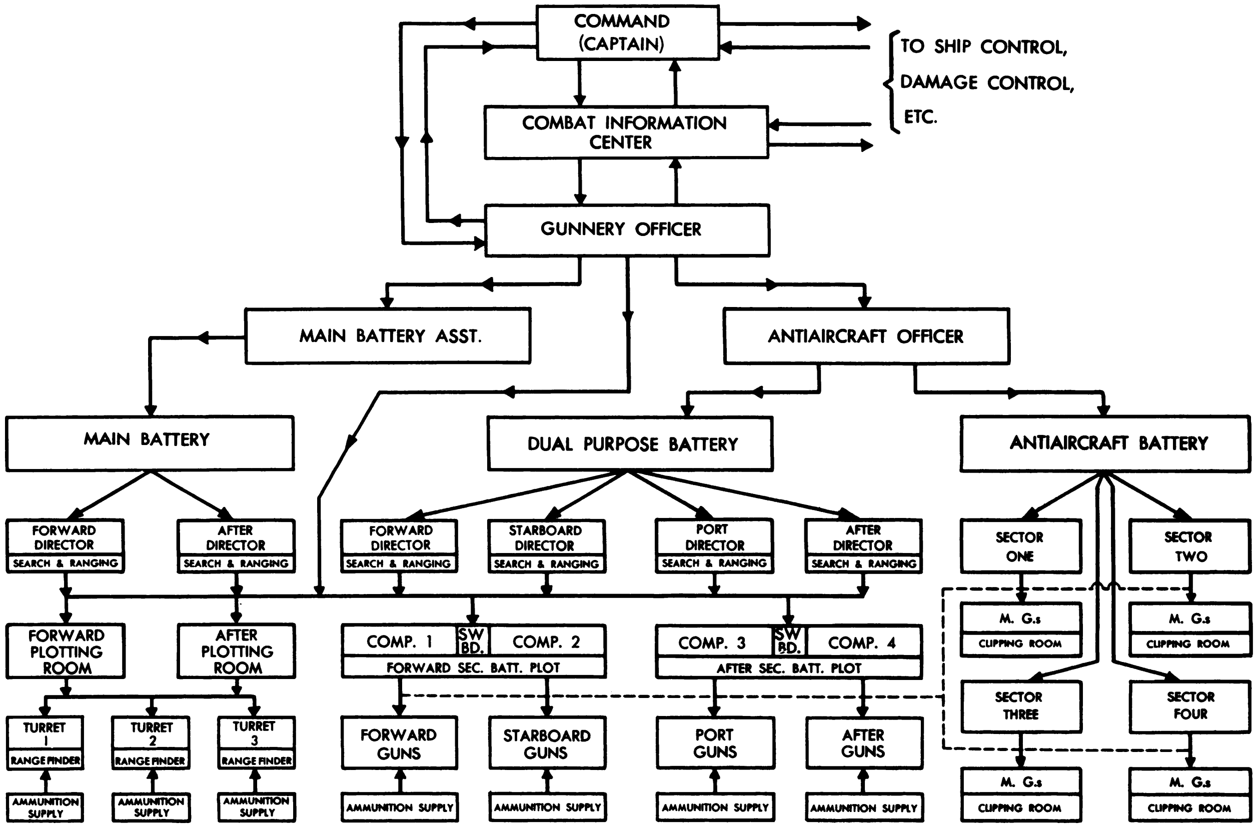


FIGURE 30A1.—A portion of a battle bill, showing the fire control organization.

3. Provide an initial or a check solution of target course and speed.
4. Warn automatic weapons of the presence or approach of hostile aircraft and small craft.
5. Aid in radar spotting.
6. Inform fire control personnel of the presence of friendly forces in the vicinity.
7. Relay to fire control personnel orders and information of direct interest from higher authority.
8. Assist in liaison with shore fire control parties or other assistants to the fire control organization located outside the ship.

30A6. Gunnery Officer

The fire control organization functions under the supervisory control of the Gunnery Officer. He usually exercises his control of the individual batteries through assistants designated as battery control officers. During battle, the Gunnery Officer is in immediate communication with the Commanding Officer, with the Gunnery Liaison Officer, and with the various battery control officers; in addition he may maintain direct communication with the officers in charge of individual main-battery stations.

In general, the duties of the Gunnery Officer may be outlined as follows:

1. He informs the Commanding Officer as to the general gunnery situation and the practicability of opening fire with the main battery.
2. Prior to opening fire with the main battery, he desginates the target on which to fire, the fire distribution to be employed, and the type and method of battery control to be used.
3. He keeps in touch with the various armament subdivisions and their activities.
4. He is advised as to casualties and directs such redistribution of personnel or rearrangement of circuits as may be necessary to maintain the maximum efficiency of the armament as a whole.

As noted above, one of the Gunnery Officer's chief functions is target designation, which is made in accordance with the Commanding Officer's instructions. In the case of a main-battery target, it is possible that there may be a special assignment from higher authority in the form of a fire-distribution signal. Similarly, in antiaircraft and small-craft defense, orders from higher authority may direct the batteries of a ship to guard a particular sector of the area around a task force or group. Thus the designation of a target may actually be originated in part or in whole from without the ship, and an order be transmitted by the Captain (or, in accordance with the doctrine, through CIC) to the Gunnery Officer. In other situations, target designation may be made by the Captain personally; for example, in directing the division of fire between two main-battery targets; or it may be in accordance with standard doctrine by the Gunnery Officer or one of his ranking assistants.

30A7. Antiaircraft battery control

Since the defense against air attack may involve more than one subdivision of the ship's armament, and since the presence of potential air attack may not be realized because of the Gunnery Officer's immediate preoccupation with surface targets, major vessels detail an officer as antiaircraft officer. His function is to coordinate the ship's antiaircraft batteries, in the course of which he may assume control of the directors and guns of any or all of those batteries which may be used for antiaircraft fire. The antiaircraft officer is frequently given the authority to open fire on hostile planes on his own initiative, without immediate and specific orders from the Commanding Officer or the Gunnery Officer.

The antiaircraft officer does not necessarily control the firing of any one battery or one group of guns personally, but acts in a supervisory capacity over the various gun groups through their respective control officers. He may designate targets, initiate a shift in responsibility for targets from one battery group to another, and generally direct the ship's AA defenses. The antiaircraft officer is usually in direct communication with the Commanding Officer and the Gunnery Liaison Officer, as well as with the sector and group control officers of the antiaircraft battery. In ships with a dual-purpose main battery, the Gunnery Officer himself may be the antiaircraft officer, or he may act as Gunnery Liaison Officer.

30A8. Battery control

Each main subdivision of the ship's armament (main battery, secondary battery, antiaircraft battery, torpedo battery, antisubmarine battery, rocket battery) is controlled by a Battery Control Officer. Each control officer is directly responsible to and in communication with the Commanding Officer, the Gunnery Officer, and, when appropriate, with the antiaircraft officer. In addition, each battery may be subdivided into groups containing two or more gun mounts (or turrets). Such a group may be controlled by an officer designated as a Group Control Officer. Such subdivision of a battery is justified because it affords greater flexibility, particularly in case of casualties or when divided battery control is necessary.

In the case of antiaircraft guns, each battery group is usually given direct responsibility for one *sector* of the area surrounding the ship, in which sector it has responsibility for protecting the ship against surprise

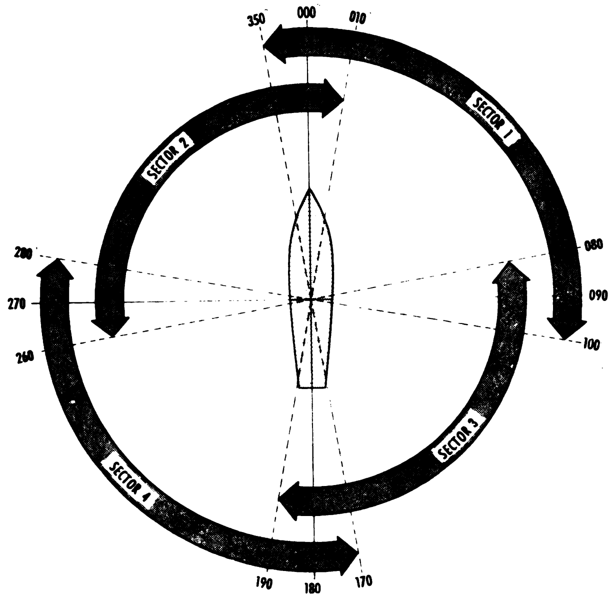


Figure 30A2.—Sector assignment of AA battery.

attack. There are usually four sectors, each covering an arc of 110°, thus allowing a 20-degree overlap of sector boundaries as shown in figure 30A2. Sector Control Officers may be delegated authority over groups of *more than one* battery at such times as those groups are assigned the same sector.

In main and dual-purpose batteries, Group Control Officers will normally be associated with individual directors, and they are most frequently stationed at the directors. Group Control Officers of other batteries may in some cases be similarly stationed, if appropriate to the equipment installed on the ship.

30A9. Turret Officer and Mount Captain

As a final step in the chain of command, each turret or gun mount is under the direct, personal, and immediate control of an officer or petty officer at the mount. In the turrets, this control is usually exercised by a Turret Officer, assisted by a turret captain (a petty officer). Commissioned officers are rarely stationed in individual dual-purpose mounts, which are normally under the direction of senior petty officers designated as *Mount Captains.* Heavy machine-gun mounts are also directed by Mount Captains, whose personal responsibilities are chiefly executive. At light machine-gun mounts, either the gunners or the range setters may be the Mount Captains.

Turret Officers and Mount Captains ordinarily direct the guns for which they are responsible under specific orders from battery, sector, or group control stations. In case of casulties, however, they may have considerable independent authority. They must be trained to take full charge of their own stations under local fire control procedures, if and when necessary.

B. Communications

30B1. Introduction

The organizational outline contained in the first part of this chapter has made it clear that efficient utilization of the ship's battery is dependent to a great extent upon efficient communications. Not only is this necessary for transmission of orders, but, as indicated in the chapters on fire control systems, communication is also necessary between the various stations cooperating in control of a single battery or group of guns. Because of this separation of elements, and because individual stations such as turrets are both sizable and noisy, the unaided human voice is not to be depended upon for reliable communication aboard a warship in action.

One method of communication is the synchro transmission system between the fire control instruments. However, synchro transmission is limited to such angular quantities as sight angle or gun train order, and is not adequate for the transmission of all types of orders or communications. Some means must be provided for spoken communication between the various elements of the fire control system and for communication by audible signals.

30B2. External communications

The fire control party is greatly concerned with the results of external communications. It is not, however, charged with the responsibility of conducting such communications. In most cases communications from outside the ship which are of interest to the fire control organization will be received by the communications organization or by CIC and relayed to the gunnery organization. There are a few exceptions to this general rule: when fire is being controlled with the assistance of a shore fire control party or with the assistance of spotters in aircraft, voice radio transmitters and receivers may be directly available to gunnery personnel. This equipment, however, comes under the cognizance of the Operations Department and is made available to Gunnery for specific use and on specific occasions.

30B3. Interior communications (IC)

The maintenance of interior communications systems is not the responsibility of the Gunnery Department aboard ship, but comes under the cognizance of the electrical division of the Engineering Department. Many of the IC circuits, however, are of primary interest to the Gunnery Department. These systems and their standard symbols are:

1. Battle telephones (JA, JB, . . . JZ).
2. Ships service (dial) telephones (J).
3. Battle announcing circuits (MC).
4. Call signals (E).
5. Train warning systems (TW).
6. Salvo signals (VB).
7. Cease-firing signals (U).
8. Turret alarms (RA).

In addition to these IC circuits, ships still use the oldest interior communications device, the voice tube. It has its limitations as to maximum practical length, and its efficiency falls off rapidly every time the tube goes around a corner, but it is simple and reliable. An example of the current use of a voice tube is to connect the mount captain's station and the upper ammunition handling room in certain dual-purpose mounts. Voice tubes are rarely used below decks, as they seriously impair watertight integrity.

Other less important types of interior communications include the teleautograph and pneumatic tubes. Even hand signals are important in some cases. They are normally used between pilot and catapult officer, by landing-signal officers in carriers, and for communicating between control officers and talkers during action.

30B4. Battle telephone systems

The most important set of interior communications circuits is the sound-powered battle telephone system. In this system the energy that creates the current which transmits the message is supplied entirely by the speaker's voice. No outside source of power is required. This system is therefore more reliable in emergencies than any of the other circuits listed above, all of which depend upon the availability of externally supplied electric power.

Battle telephones are set up as groups of connected stations rather than as individual stations. When a telephone is plugged into its jackbox it is automatically connected with all the other stations on that circuit which are at that time plugged in. The connected groups are called *circuits*. Circuits in turn are organized into systems. The three systems of battle telephone circuits are (1) primary circuits, (2) auxiliary circuits, and (3) supplementary circuits. A standard method of designating individual circuits in these systems is in effect. It is not necessary to learn the names and circuit designations of the large number of circuits which will be found in a major ship. Gunnery personnel will, however, find it appropriate to know the circuit designations of all circuits at their individual stations and of all circuits directly concerned with their own battery. On all except the largest ships they will probably find it expedient to know all primary circuits on the ship.

There is a standard method of designating by symbols every circuit in each of the three systems. This method is as follows: The letter J indicates that the circuit is a telephone system; *primary* circuits are assigned individual letters following J as, for example, JA, JB, *etc.* The second letter designates the function of the circuit.

Typical letter dual combinations are as follows:

JA—Captain's Battle Circuit.
JC—Battery Control Circuit.
JK—Fuze Setters' Circuit.
JW—Range Circuit.

Numerals preceding the two letter designations are used to identify individual circuits with the same function but pertaining to different batteries, or similar subdivisions in the case of non-gunnery circuits. For gunnery circuits, number 1 so used indicates the main battery; number 2, the dual-purpose battery; number 4, the heavy machine-gun battery, *etc.* Numbers following the two letters are used to indicate the group within a battery in such circuits as are divided into battery groups. Thus the total designation of a primary circuit may be, for example, 2JW2, indicating Dual-Purpose Battery Range Circuit, group 2.

Auxiliary battle telephone circuits are assigned circuit numbers similar to their primaries, but preceded by the letter X; for example, XJA for the Captain's Auxiliary Battle Circuit, or X1JC for the Auxiliary Turret Control Circuit. Circuits of the *supplementary* telephone system are assigned designations such as X1J, X2J, *etc.*, through X407J.

30B5. Primary circuits

Primary circuits are the main channels of communication for controlling armament and maneuvering the ship. When the ship is at general quarters, each station on a primary circuit is normally manned by either the officer in charge of the station, one of his assistants, or a telephone talker reporting to the officer in charge of the station. These men normally wear headsets, so that they may maintain a continuous watch on the lines. In addition to those headsets which are plugged into individual circuits, control officers may wear headsets which are connected to *selector switches* which enable them to cut into any one of several circuits in which they are directly interested. At other stations control officers may have available to them handsets with which they may intermittently communicate personally on one or more circuits normally covered for them by talkers.

All primary circuits for the ship's armament can be controlled and interconnected by means of switchboards located in the plotting rooms, as well as by the selector switches noted above. By means of these switchboards, control circuits may be shifted to parallel the transmission of information or orders by synchro. They also make it possible to tie circuits together, as may be done during wartime cruising when not all stations are fully manned, or to provide emergency communication facilities between stations not normally connected, and to isolate circuits or individual stations when necessary as, for example, in case of casualty.

In the plotting room one fire controlman is normally assigned to the fire control and battle telephone switchboards. When control is shifted from one station to another, he will reset both boards. For example, suppose that the Gunnery Officer aboard a cruiser has ordered that the forward main battery be assigned to the control of the dual-purpose battery director. This involves not only changing over the synchro and indicator circuits of two turrets to connect them to the dual-purpose battery synchro and indicator circuits, but also connecting part of the main-battery control telephone circuit (1JC) with the forward dual-purpose battery control circuit (2JC1). This is done by making cross-connections on the switchboards. The crew in the plotting room takes care of the plugging and switching involved. Personnel in the director and in the turrets know what is going on, but they play no part in the actual switching operation. The switchboard crew would also take care of interconnecting other affected circuits, such as the two fuze setter's circuits (1JK and 2JK), and the range circuits (1JW and 2JW), as required.

30B6. Auxiliary circuits

The auxiliary battle telephone system is a stand-by system which parallels the most important primary circuits and is intended for use in case the latter become inoperative. It does not have switchboards. Therefore, in case of a casualty at the switchboard, the auxiliary circuits may still be available for use. As the auxiliary battle telephone circuits are not ordinarily continuously manned, they are generally equipped with handsets rather than headsets.

30B7. Supplementary battle telephone circuits

Supplementary circuits are those either not important enough or not extensive enough to be included in the primary system. Most supplementary circuits include only two or three stations. They are equipped with handsets and are usually accompanied by circuit-E buzzer systems. In mounts and turrets most supplementary circuits are concerned with ammunition service. Thus the supplementary circuit found in 5-inch enclosed mounts is the X17J, which connects the top and bottom of the lower ammunition hoists. Turrets may have more elaborate supplementary telephone circuits for internal use. The *Salem* Class 8-inch turret has nine supplementary circuits. One of them connects the Turret Officer with gun positioning and sight-setting personnel, and the others connect various stations of the ammunition supply system with the Gun Captains and Turret Officer. Supplementary battle circuits have no switchboards, but in some cases there are switches available which can be used to interconnect different supplementary circuits or to tie them into primary circuits.

Emergency communications systems are usually provided on board ship. These consist of telephone lines with sound-powered telephones attached. This emergency equipment is generally kept on reels located at strategic points throughout the ship, and the phones may be unreeled to serve as a stand-by in case of failure of normal sound-powered communications.

30B8. Care of instruments

In order that sound-powered telephone equipment may be ready for any emergency, it must be kept in good condition and handled properly at all times.

There are two types of sound-powered phone sets, the handset and the headset. The handset telephone looks like a "French type" telephone, except that in the middle of the bar connecting the transmitter and receiver is a push button which must be held down whenever the user is speaking or listening. This instrument is used as an emergency phone and also as a service phone (on supplementary circuits) between such places as the bridge, the wardroom, and ship's offices.

The headset telephone is the standard battle telephone. It consists of a pair of earphones and a transmitter. The earphones are on a spring-metal clamp or fabric harness that fits over the talker's head. The transmitter, held in an adjustable yoke, is mounted on a breastplate. The breastplate is hung on a strap around the talker's neck. Also there is on the breastplate a small box where the wires are joined together. One of the leads is short and goes to the mouthpiece. The other two leads go to the earpieces. Connected to the breastplate is a long, heavy lead at the end of which is a metal plug which is inserted into the appropriate jackbox to connect the phone to the rest of the circuit. In case of a casualty to the transmitter on a headset phone, it is possible to speak into one earpiece, while listening through the other one.

When the headset telephones are in use, the leads should never be permitted to carry the weight of the instrument or of any part of it. When securing phones, the following standard procedure is used:

1. Remove plug from jackbox. Never yank the plug out by the cord.
2. Screw the cover on the jackbox; otherwise moisture, spray, and dirt may cause a short circuit.
3. Remove the headband and hang it over the transmitter yoke.
4. Coil the plug lead from the phone to the plug clockwise, about eight to ten inches in diameter.
5. Wind the neck strap around the coil and headband, and secure the ends to the breastplate, keeping back of breastplate together with headband and coil.
6. Put the phones in the stowage box provided, making sure that no part of the phones or cords sticks out of the box.

30B9. Battle telephone procedures

Efficient fire control communications are not attained merely by the installation of a satisfactory system of telephones. It is also necessary for all personnel using telephones to follow standardized procedure. Enlisted men who are to be used as telephone talkers are given careful training. In a fire control organization, however, many officers and ranking petty officers man telephones personally, and it is just as necessary for them to use correct procedure as it is for them to train the talkers in delivering and transmitting messages properly.

Fire control telephone circuits are party lines providing communications between numerous stations. On some of these circuits there may be as many as 12 parties on a line at the same time. When any one officer or talker transmits a message, all the others receive it. Under these circumstances each transmission must be of the utmost brevity consistent with clarity. In action or at any other time, conversation in the usual sense has no place on a battle telephone circuit.

The demand for brevity has resulted in the development of numerous stereotyped phrases and modes of expression. They constitute what may be termed the "fire control language." Familiarity with this language can be acquired only through actual experience, but certain elements may be learned as a preliminary to such experience.

30B10. Call and acknowledgment procedure

An important feature of the fire control language is the manner of calling a station and of replying or of acknowledging. Ordinary practice on a telephone conversation is to call a person by name and to await acknowledgment before proceeding with the message. This is logical when the party calling has no assurance that the party called is listening. On a fire control circuit this question does not exist. The first step in manning battle stations is establishing communication. While the ship remains at general quarters, communications must be maintained as long as communication lines remain intact. If one station has information to transmit to another, it is unnecessary to call that station and receive an acknowledgment before proceeding with the message. It is presumed that all stations are on the circuit and listening continuously.

In originally establishing communication, the officer or talker at the controlling station (usually the senior station on the line) will ask whether other stations have their telephones manned. To do this he transmits, "All stations; Control (Plot, Sky Forward, *etc.*); testing." Each station on the line acknowledges in a standard order "Turret One; aye, aye," "Turret Two; aye, aye," etc. If a station does not answer after a brief pause, the next station will acknowledge and the station omitted will come in at the end of the sequence or will report upon manning its telephone.

Once a circuit is manned, if it is desired to address a message to any one station, the correct procedure is to give the call of that station, followed by the identification of the station transmitting and then followed, without pause, by the message. The station called acknowledges by repeating his own call followed by "aye, aye," which means, "I have received the message transmitted, understand it, and will comply to the best of my ability." For example, a dual-purpose battery Director Officer may transmit, "Mount fifty-two; Sky One; train centerline." The Mount Captain will answer, "Mount fifty-two; aye, aye."

If the station transmitting the message does not receive acknowledgment immediately, it repeats the call and message. If, after several repetitions, no acknowledgment is received, the calling station will establish communication by some other means and determine the casualty. If the message is heard by the station addressed, but not understood, that station should say at once "Repeat," and the transmitting station should then repeat both the call and the message. When a message is addressed to several stations simultaneously, the procedure is the same as for a single station except that a collective call, such as "All Mounts," or the individual calls of the several stations precede the message; acknowledgment is made in proper sequence as soon as possible. During stand-by intervals, it may be desirable to communicate with a station for the purpose of testing the circuit. If a station is addressed solely for test, the procedure is to speak the call as usual, followed by the word "testing." The acknowledgment is made in the usual way.

No station ever gets off the circuit, even temporarily, without reporting to the controlling station. When necessary to interrupt communications, a station will transmit such a message as "Control; Sky Two shifting phones," and will wait for an acknowledgment from the controlling station before effecting the shift. When at the end of an alert or drill period permission is given by the controlling station to secure the telephones, each station reports as it goes off the line in this manner, "Director Forward; Plot securing phones."

30B11. Circuit discipline

It is the responsibility of the controlling station to see that the circuit is always clear and available for emergency use. The officer or talker at the controlling station monitors the circuit and is expected to stop unnecessary conversation by transmitting the phrase "Quiet on the line." This same phrase may at times be used by other stations when it is necessary to interrupt another transmission in order to pass an emergency message.

All messages on the circuit must be made in official language. The use of unauthorized expressions, including slang, seriously interferes with the speed of transmittal of information. Such courtesy words as "Sir" and "please" are not used. Letters are not spoken as letters, but should be referred to by their names in the Navy phonetic alphabet. Numbers are spoken differently, dependent upon their meaning, as set forth in the next article.

30B12. Transmission of numerals

The manner of speaking numerals is varied in order to indicate more clearly whether the number transmitted is an expression of bearing, range, or position angle.

1. In transmitting *bearing,* all ciphers are pronounced "zero"; for example, "bearing zero eight zero," or "bearing three one zero."

2. In transmitting *range,* ciphers are pronounced "oh," or when appropriate, are indicated by use of the word "hundred" or "thousand," as shown in the following examples:

Range 700	"Range seven hundred."
Range 3,000	"Range three thousand."
Range 3,500	"Range three five hundred."
Range 10,200	"Range one oh two hundred."
Range 3,750	"Range three seven five oh."
Range 21,050	"Range two one oh five oh."

3. In transmitting *position angle,* all numbers are spoken as in ordinary conversation, thus "POSIT twenty" or "POSIT thirty-five."

30B13. Rules for talkers

Talkers hold very important positions, yet they cannot be expected to possess the experience and judgment of the officers for whom they are acting. In order that there may be no possibility of having the substance of a message altered as a result of misinterpretation by a talker, the responsibility for framing a message rests with the officer originating it. Once delivered to a talker, it must be transmitted in *exactly the same words,* and the talker receiving the message at the other end must repeat it to the officer concerned *in the exact form in which it is heard.* In brief. there are two primary rules governing fire control communication through talkers.

1. The person originating the message must state it in the exact words in which it is to be transmitted.

2. The talker transmitting the message must repeat the exact words of the originator, and the talker hearing the message must repeat word for word what he hears.

Acknowledgements belong in the same category as messages. An acknowledgement signifies that the message has been heard and *understood.* It is the responsibility of the person addressed, not of his talker, to understand the message, and it is he who must originate the acknowledgment. A partial exception to this rule applies in the case of the transmission of data, in which case the acknowledgment consists of a repetition of the message. For example, Sky One transmits the target angle to Plot. The correct message is "Target angle two seven zero," and the correct acknowledgment is an exact repetition of the message.

Another exception applies when a message is not heard distinctly, or not understood. If a talker does not hear a message distinctly, he must call for "repeat." If the person addressed does not understand the message, he must also call for "repeat." It is to be noted that the responsibility for understanding a message does not rest with the talker, and as long as the talker hears a message distinctly, he must repeat it exactly as heard, whether or not he comprehends its significance. It is the duty of the person addressed to determine whether or not the message is intelligible. Much confusion and loss of time result from talkers asking for a repeat on messages which they do not understand, but which would probably be clear to the officer addressed. Of course it is highly desirable that talkers should understand all messages that they are likely to transmit and receive; the handling of messages thereupon becomes much more accurate and rapid.

30B14. Ship's service telephones

The ship's service telephone system or automatic telephone (circuit J) is operated like the conventional dial telephone systems found ashore. It is electrically powered, and has a central switchboard and dialing apparatus for making connections between stations. Because in general only two stations can be on one circuit at one time, and because the system is vulnerable to power failure, the ship's service telephone system is not to be depended upon under battle conditions. However, there are ship's service telephones in most fire control stations and in most of the larger mounts and turrets. They are useful for administrative traffic.

30B15. Battle announcing systems

There are two characteristic types of battle announcing (MC) systems. One of these is the *central amplifier system,* consisting of one or more microphones and variously situated loud speakers. The other type is the *intercommunications system,* which is designed to provide two-way transmission of orders and information between stations. Both types are dependent upon electronic amplification.

The main announcing system for the ship is the 1MC, or General Announcing System, operating under the authority of the Officer of the Deck, over which word can be passed to all parts of the ship. Other central amplifier systems of particular interest in fire control include the 11MC to 16MC which provide for transmission of turret control orders and information between the Turret Officer and each gun station, the machinery deck, the projectile-handling deck, and the powder-handling deck. It also provides for a tie-in to circuit 1MC for automatic transmission of general alarm and chemical-attack alarm signals to turret personnel. Circuits 11MC to 16MC are installed in turrets 1 to 6 respectively, as applicable. The dual-purpose battery announcing system, 17MC, provides similarly for transmission of gun-control orders from dual-purpose battery director stations to dual-purpose gun mounts. Its reproducers can also be tied in with circuit 1MC and, in addition, they are used for the transmission of salvo and cease-firing signals to the gun mounts.

Central amplifier-type MC systems have the advantage over telephone communication in that they transmit orders or information simultaneously to all personnel at a station. Since, however, their continued use results in excessive noise levels, they are normally employed only for urgent and simple messages.

Intercommunicating systems of particular interest to gunnery personnel are as follows:

Captain's Command Announcing System, circuit 21MC. This system provides for two-way transmission of ship control orders and information between interested key stations, including the primary and secondary conning stations, main-battery control stations, air defense stations, Combat Information Center, and others.

Combat Information Announcing System, circuit 20MC. This system provides for the transmission of combat information, especially radar warning information, between CIC and conning stations, battery control stations, and the plotting room.

Sonar Control Announcing System, circuit 27MC. This system provides for two-way communication between sonar equipment stations and between these stations and CIC, the bridge, and the ASW attack station.

Intercoms, like general announcing systems, have the advantage of attracting the attention of all hands at a station simultaneously. They similarly have the disadvantage of raising noise levels, although this disadvantage is lessened by the fact that messages are heard only at the one station to which addressed. They are used to parallel telephone communications in the case of urgent and short messages, and are also frequently used to regain communication when a station fails to answer on a battle telephone circuit.

30B16. Signal systems

Telephone and announcing systems are primarily voice communication systems. Besides these, modern naval armament is equipped with several systems of signals for special purposes:

1. *Train warning signals.* Safety regulations require that before any turret or enclosed mount is moved in train, a warning signal must be sounded so as to inform personnel to keep clear. The only exception is that the signal need not be sounded during general quarters. The train warning signal circuit is independent of all other IC circuits, and consists of a push-button control switch at the Mount Captain's station, bells outside the mount, and the necessary wiring and power supply.

2. *Call-signal system.* The call-signal system (circuit E) parallels the supplementary battle telephone circuits and voice tubes. It is not used independently; it always parallels a voice communication line. It consists of power-supply units, push-button switches, and buzzers or bells so interconnected that, to attract the attention of a man at the other end of a voice tube or unmanned telephone, one may press the button to sound the signal at the distant station.

3. *Cease-firing signal.* The order to cease fire is normally given by sounding a special signal consisting of a loud, low-pitched, penetrating buzz produced by an electrically driven device, in addition to transmitting the order in words. This signal may be trans-

mitted over independent reproducers at the mounts or turrets, or, as in the case of dual-purpose mounts, over the same loud speakers as those used for the 17MC. In certain machine-gun systems this circuit can be so interconnected with the headsets of gun crews' telephones that they will hear the cease-fire signals in their phones as well as over the reproducers installed at the mounts.

4. *Salvo signals.* The salvo signal is a variable-pitch buzz produced electrically by special apparatus. In turrets, salvo-signal reproducers are installed where they can be heard by the crew in the gun compartments. In dual-purpose battery mounts the signal is transmitted through the 17MC reproducers. There is no salvo-signal circuit for the machine-gun battery, as machine guns do not fire in salvo.

5. *Intraturret emergency alarm.* The intraturret emergency alarm is an independent circuit used to issue warning of danger or of serious casualties in a turret. It consists of a number of small electrically driven sirens which can be set in operation from any one of several stations in the turret. The Turret Officer's booth has a switch for silencing the sirens after they have been set off.

Chapter 31

JUNIOR GUNNERY OFFICER

A. Gunnery Department

31A1. Basic plan of organization

The complement of a ship is composed of such numbers, ranks, and ratings of officers and men as are required to operate the ship most efficiently. A ship's organization is essentially a war organization, developed on the theory that ships should operate in peacetime with an organization that can be expanded quickly without basic change when the transition to a wartime operating condition becomes necessary. It is based on a grouping of functions and personnel that is intended to reduce to a minimum both the possible overlapping of responsibilities and the duplication of personnel.

This does not imply that administrative organization, even in wartime, is parallel with the battle organization discussed in the preceding chapter. It is necessary for the battle organization to provide for short cuts in order to save time in the transmission of orders. It is also necessary for battle organization to provide for alternative channels to be used in case of casualty. The administrative organization can be rather more formal.

31A2. The Gunnery Department

On board ships whose offensive characteristics are those relating primarily to ordnance or aircraft, the Gunnery Officer heads the Gunnery Department and the First Lieutenant is an assistant to the Gunnery Officer, with direct responsibility for deck seamanship.

On board other ships, the First Lieutenant heads the Deck Department and the Gunnery Officer is an assistant to him.

The functions of the Gunnery Department are as follows:

1. Operation, maintenance and repair of armament.
2. Launching and recovery of aircraft (on ships without an Air Department).
3. Operation and maintenance of assigned electronic equipment.
4. Antisubmarine warfare.
5. Mine warfare.
6. Deck seamanship.
7. Operation and upkeep of boats.
8. Cleanliness and upkeep of spaces assigned to the Gunnery (or Deck) Department, including ship's exterior.
9. Care and storage of all ammunition.

While the functions of the Gunnery Department are many and varied, it must be remembered that the primary reason for its existence is the armament that the ship carries. This armament must be maintained in a constant state of readiness, and it must be effectively operated to deal destruction or damage to the enemy.

The Gunnery Department divisions are designated First, Second, *etc.*, the lowest numbers being assigned to the division whose responsibilities include maintaining the forward battery of the largest caliber guns assigned to the ship. Numerals are then assigned in ascending order from forward aft, with odd numbers starboard, until all divisions of the main battery have been assigned designators. The process is repeated for batteries of the next smaller caliber guns until all battery divisions have been assigned designators. The next higher number is then assigned the Marine detachment, if one is attached to the ship. The letter "F" is used to designate the Fire Control Division, with a second letter added when more than one fire control division is assigned. Thus "FA" designates the Antiaircraft Fire Control Division and "FM" the Main Battery Fire Control Division. On ships operating aircraft, other than aircraft carriers and seaplane tenders, the Aviation Division is assigned to the Gunnery Department and is designated by the letter "V". When only one division is assigned to the Gunnery Department, the numeral "1" is used as a designator.

31A3. Duties of the Gunnery Officer

The Gunnery Officer is charged with the supervision and direction of the employment of the ordnance equipment and the equipment associated with deck seamanship. He is responsible for the training, direction, and coordination of personnel assigned to his department. He assists the Executive Officer in the planning and conducting of drills and exercises. He is responsible for ensuring that all the functions of the Gunnery Department listed in article 31A2 are properly performed.

31A4. The Gunnery Officer's assistants

In addition to the First Lieutenant, the Commanding Officer may assign assistants to the Gunnery Officer, consistent with the type of ship, as indicated below:

1. Main Battery Officer.
2. Fire Control Officer.
3. Air Defense Officer.
4. Assistants to the First Lieutenant.
   a. Boatswain.
5. Torpedo Officer.
6. Mine Warfare Officer.
7. Aviation Officer.
8. Marine Officer.
9. Antisubmarine Warfare Officer.
10. CIC Liaison Officer.
11. Deck Division Officers.

On major vessels, officers of considerable experience are usually assigned as Main Battery Officer, Fire Control Officer, and Air Defense Officer. Where available, officers of specialized experience are assigned to such positions as Torpedo Officer and Mine Warfare Officer. The Aviation Officer and Marine Officer are, of course, billets limited to special personnel. With these exceptions, however, a junior officer just reporting on board ship may well be assigned to any one of the listed administrative billets. If sufficient experienced personnel is available, the junior officer's assignement will be as assistant to the occupant of one of these billets.

While a junior officer in the Gunnery Department will have many duties of purely administrative nature such as those discussed in this chapter, his primary concern will be with his gunnery battle station. Again, a wide variety of assignments faces the newly commissioned officer. He may be assigned to any one of the following battle stations, depending upon the type of ship and upon the availability of experienced officer personnel:

1. Turret Officer or Junior Turret Officer.
2. Dual-Purpose Battery Group Control (Director Control) Officer, or Illumination Officer.
3. Machine-Gun Battery Group Control Officer.
4. Main-Battery Director Officer.
5. Assistant Plotting-Room Officer (main or dual-purpose battery).
6. Torpedo Control Officer.
7. Antisubmarine Battery Officer.

B. Administrative Duties

31B1. General

First of all, the junior gunnery officer will find himself confronted with what appears to be an intricate maze of administrative details. He will have inspections, tests, and checks to be made on various pieces of ordnance equipment; he will have inventories to take and spare parts and gear to order; he will have seemingly endless reports to make; he will have countless little problems within his division which require solution. Moreover, he will have watches to stand, logs to write, and will probably have one or more collateral duties not necessarily related to Gunnery Department work. All this will be in addition to his primary duty of developing and maintaining that part of the ship's armament for which he is responsible to the highest degree of readiness as regards both personnel and material.

A junior officer assigned to the Gunnery Department will be further assigned to a gunnery division and consequently should be familiar with the duties of a Gunnery Department division officer.

Gunnery Department division officers are governed by *Navy Regulations* and the *Ship's Organization Book*. *Division Officer's Guide* contains a summary of what must be accomplished in the organization, training, and direction of a ship's divison, and is a useful guide to the leadership aspect of the division officer's duties.

In addition to the responsibilities and duties prescribed in *Navy Regulations,* Gunnery Department officers, under the Gunnery Officer, are responsible for the proper performance of the following functions:

1. Ensuring, through a properly conducted training program, that all personnel of the division are properly trained in their duties and ready for action.

2. Ensuring that all spaces and equipment assigned to the division are maintained in the required condition of upkeep and cleanliness.

3. Ensuring that all division personnel are thoroughly instructed in pertinent safety precautions. This responsibility does not end with the publication of safety precautions; the division officer must also ensure that all safety precautions are carried out both in spirit and to the letter.

4. Informing the Gunnery Officer of any conditions in the division that may decrease efficiency of division personnel or equipment, particularly if any ordnance equipment in the division is, for any reason, not ready for battle.

Division officers are assigned additional duties pertaining to the specific assignment of their divisions in the *Ship's Organization Book,* or as the Gunnery Officer may see fit. Each junior division officer is required to be thoroughly familiar with all duties, responsibilities, and activities of his division. In addition, each junior division officer is assigned certain specific duties for which he is responsible to the division officer.

31B2. Training

No single function is more important than the training of personnel. The most expensive and best designed equipment is useless unless the men stationed at it know how to maintain and operate it intelligently. Training starts at the lowest level and, like a woman's work, is never done. It must be a continuous, progressive process, objectively designed to produce realistic problems and conditions, and intelligently handled to create and maintain enthusiastic interest.

As one of the duties of the Gunnery Officer is the supervision and direction of the employment of ordnance equipment, so is it the junior officer's duty to implement this program by proper training of personnel. There are several requisites for an effective training program. The junior officer must be completely familiar with the ordnance equipment for which he is responsible. This includes not only operating procedures, but theory and design characteristics as well. He must ensure that petty officers and key personnel, who will conduct instruction on station, are themselves competent and well informed. The junior officer must carefully appraise his men and assign them stations in accordance with their capabilities, both mental and physical. Frequently, valuable information can be obtained from the service record of each man, which is available in the Executive Officer's office. A division notebook, which should contain detailed data on each man in the division, as well as the division station bill and battle bill, is invaluable in this instance.

Finally, the junior officer cannot neglect his own training. He must apply himself continually and learn not only his job but the jobs of those who are immediately senior to him. When the time comes for fleeting up, he must be ready. He must also learn how his division fits into the Gunnery Department and in turn how that department functions in the ship's organization.

31B3. Material maintenance

Just as important as the training of personnel to operate ordnance equipment, is the proper maintenance of that equipment, so that it will be serviceable when needed. Modern ordnance equipment is extremely complex and requires constant check, test, lubrication, and adjustment to keep it in first-class operating condition. Much of this routine, day-to-day, week-to-week work can be called "preventive maintenance"—in other words, attempts to discover and eliminate possible sources of trouble before trouble actually occurs.

The Bureau of Ordnance furnishes, with each ordnance installation, publications which outline maintenance procedures. These publications are readily available, but it is the junior officer's responsibility to see that the procedures outlined in them are followed by the gunners' mates and fire control technicians.

Frequently, Type Commanders will issue check-off lists which detail the items of work that are to be done daily, weekly, monthly, *etc.* As work logs are kept on each piece of ordnance equipment, the junior officer can quickly check the work accomplished each week. He should not, however, be satisfied with paper-work checks. The junior officer should get around his spaces during working hours, find out what his men are doing, what items or pieces of gear are troublesome, and what can be done to overcome the difficulties. He can also learn much about his equipment if he is present while checks, tests, cleaning, and lubrication, are going on.

31B4. Repairs

Casualties will occasionally occur even to the best equipment, thus necessitating repairs. A repair is defined by *Navy Regulations* as "work necessary to restore a ship or article to serviceable condition without change in design, materials, number, location, or relationship of the component parts."

Repairs are divided into three classes according to the agency performing them: *i. e.,* ship's force, repair ship, or naval shipyard. Quite naturally, the extent of repairs that can be accomplished by ship's force on small ships is limited by a lack of facilities and personnel. A repair ship has more elaborate repair facilities and personnel experienced in repair work, and can accomplish most work not of a major nature. The naval shipyard, of course, is capable of handling any major repair item. An Ordnance Repair Card, such as the one shown in figure 31B1, is used to facilitate the accomplishment of repairs.

The general class "repairs" also includes the "alteration equivalent to repair." This type of work item includes the substitution of a slightly different article or material for one which must in any case be repaired or replaced as a consequence of damage or wear. The definition of "alteration equivalent to repair" is a very narrow one and should never be used to obtain improved equipment in place of older equipment which is still in usable condition.

31B5. Alterations

An alteration is defined by *Navy Regulations* as "any change in the hull, machinery, equipment, or fittings which involves a change in design, materials, number, location, or relationship of the component parts of an assembly regardless of whether it is undertaken separately from, or incidental to, or in conjunction with, repairs." No alteration shall be made to any ship or article on board until specifically authorized by the Bureau concerned.

Alterations of such extent as materially to modify the military characteristics of a ship may be authorized only by the Chief of Naval Operations. When so authorized, they are issued by the Bureau of Ordnance or such other technical bureau as may have cognizance of the material concerned, as serially numbered NAVALTS. Other authorized alterations to ordnance equipment are issued by the Bureau of Ordnance as serially numbered ORDALTS. Both NAVALTS and ORDALTS contain complete descriptions of the changes to be accomplished. Information is included on the purpose and priority of the alteration; the agency to perform it; the procurement of material; the disposition of discarded material, if any; the weight change, if any; and all necessary plans, diagrams, and specifications. This information is filed on an Ordnance Alteration Card as shown in figure 31B2. Upon completion of an ORDALT, an Ordnance Completion Card (fig. 31B3) is forwarded to the proper commands.

31B6. Current Ship's Maintenance Project

In order to have an accurate, up-to-date picture of all outstanding repairs and alterations, each department on board ship maintains a *Current Ship's Maintenance Project* (CSMP) Separate files are maintained for repairs and alterations.

The junior gunnery officer should become familiar with the CSMP as soon as possible, and see that entries pertaining to equipment for which he is responsible are promptly made. Whenever a piece of equipment requires repair, a complete brief of the existing condition should be drawn up, including an analysis of the deficiency and an estimate of the work necessary to restore the article to serviceable condition.

All outstanding applicable alterations are also listed in the *Alteration and Improvement Program* (A and I Program) which serves as a ready summary for administration purposes. This program does not include the same amount of technical detail about the alterations as does the CSMP.

Likewise, when authorizations for alterations are received from the Bureau, prompt entry should be made in the A and I Program and the alteration CSMP. Thus, when a ship is scheduled for repair-ship availability or shipyard overhaul, work lists can be quickly compiled from the Current Ship's Maintenance Project.

31B7. Ordnance History

A complete record for each piece of equipment with its mark, mod, serial number, name-plate data, and all casualties, repairs, and alterations thereto must be kept by the Gunnery Officer. Thus the maintenance and alteration status of the various batteries can be determined easily by examining the record. This record is called the Ordnance History (fig. 31B4). The junior officer will find that it is his responsibility to keep up this record for all equipment which falls under his personal cognizance. The form for this record varies with different ships, and the new officer must acquaint himself with the type used in the Gunnery Department on his ship.

Most of the information which is entered into the machinery history is obtained from the battery and fire control logs. Battery logs, which are usually maintained by the senior petty officer in charge of each type of equipment, under the direct and close supervision of the division officers, show the work accomplished on the equipment, test results, alignment data, etc. It is a painstaking task to ensure that the logs are properly kept up day by day, but only constant checking will result in a proper and complete history. Such entries as "routine tests carried out" are better avoided. It is especially important that logs and records should be carefully kept during overhaul periods (when equipment is undergoing the largest number of changes and repairs), even though at this time it is most difficult to do so. Such occasions coincide with leave periods, and officers remaining aboard double up to cover all billets, with the result that some duties may not be adequately performed.

OP 1887 sets forth the detailed procedure for maintaining all essential gunnery records, and all officers assigned to gunnery duties must become thoroughly conversant with this publication. While studying OP 1887 one should pay particular attention to the function of each log and record rather than to its form, for the forms are standardized and are readily available on board all ships.

C. Sources of Information

31C1. General

It has already been pointed out that modern ordnance equipment is extremely complex gear. It has been designed to meet certain specifications based on the best assumptions as to the type weapons the enemy will use against our Navy. A great deal of time and money as gone into the development of various fire control systems, guns and ammunition, and the component parts thereof.

To ensure that this expensive material is properly maintained and handled, the Bureau of Ordnance issues various publications to standardize the methods and practices employed throughout the fleet.

Likewise, to ensure standardization of tactical employment of armament, fleet and type doctrines are published by cognizant commanders and issued to ships of their command.

All these publications are carried aboard ship and must be studied by the junior officer. They vary in classification from unclassified to secret, but for the most part are confidential.

Confidential nonregistered publications will be in the custody of the Gunnery Officer and may be drawn from the Gunnery Office. Secret and confidential registered publications will be held by the officer in charge of registered publications (an assistant to the Communications Officer). They may be drawn by individual officers on custody receipt.

A more recent classification, applicable to certain types of publications, including some training publications, is the classification "Confidential—Modified Handling Authorized." Publications falling within this classification may be handled and stowed less rigorously than confidential publications, although adequate protection must still be given them. Individal instructions are promulgated by the command.

31C2. Bureau of Ordnance Manual (BuOrd Manual)

The *Bureau of Ordnance Manual* is broad in scope. It is designed as the basic directive publication for the Naval Ordnance Establishment and deals with naval ordnance material, afloat and ashore. It contains information which the service at large needs to know. The particular target of the manual is the Fleet.

The following portions of the manual are aimed particularly at the Fleet:

1. Sources of ordnance information and specific information of wide interest and value.
2. References to specific publications of interest and value.
3. Expression of policy of assistance to the Fleet.
4. Lists of media for technical training.
5. Specific coverage of safety precautions.

The manual contains information relative to the broad responsibilities of the Bureau of Ordnance and its functions in discharging those responsibilities.

The purpose of the *Bureau of Ordnance Manual* is briefly summarized below:

1. To place on record information calculated to assist in effecting the maximum efficiency of ordnance material.
2. To encourage officers in a thorough study and understanding of all details of ordnance activities, materials, and equipment under their charge; and to provide basic information to facilitate such study and understanding.
3. To provide a means by which constructive criticism and suggestions may be made by the service at large concerning ordnance activities and ordnance materials and equipment.
4. To provide a common nomenclature and method for standard usage in official correspondence and in instructions, both written and oral, concerning ordnance material and ordnance activities.

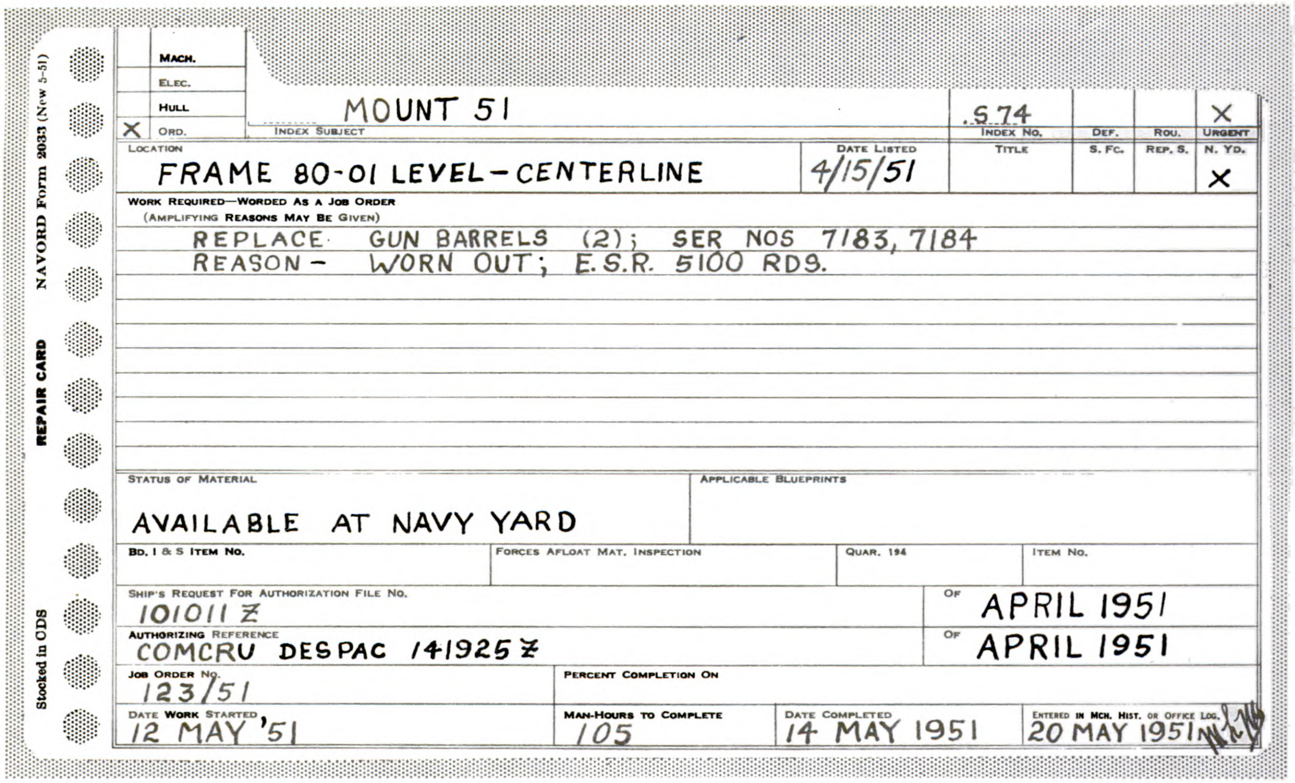
The treatment of ordnance material as handled in the *Manual* is general and basic. For instance, for full information and complete details of a particular turret or gun it will be necessary to refer to the appropriate Ordnance Pamphlet, a publication which will be discussed later.

31C3. Instructions and Notices

Bureau of Ordnance Instructions and Notices disseminate information on (1) general policy matters of the Bureau; (2) operating procedures, capabilities and limitations of ordnance equipment; (3) and changes to the *Bureau of Ordnance Manual.*

31C4. Ordnance Pamphlets (OP's).

Ordnance pamphlets contain detailed information on the description and maintenance of ordnance equipment. A separate Ordnance Pamphlet is issued for each unit of ordnance equipment; in addition, other



REPAIR CARD NAVORD Form 2033 (New 5-51)

Stocked in ODS

Mach.
Elec.
Hull
X Ord.

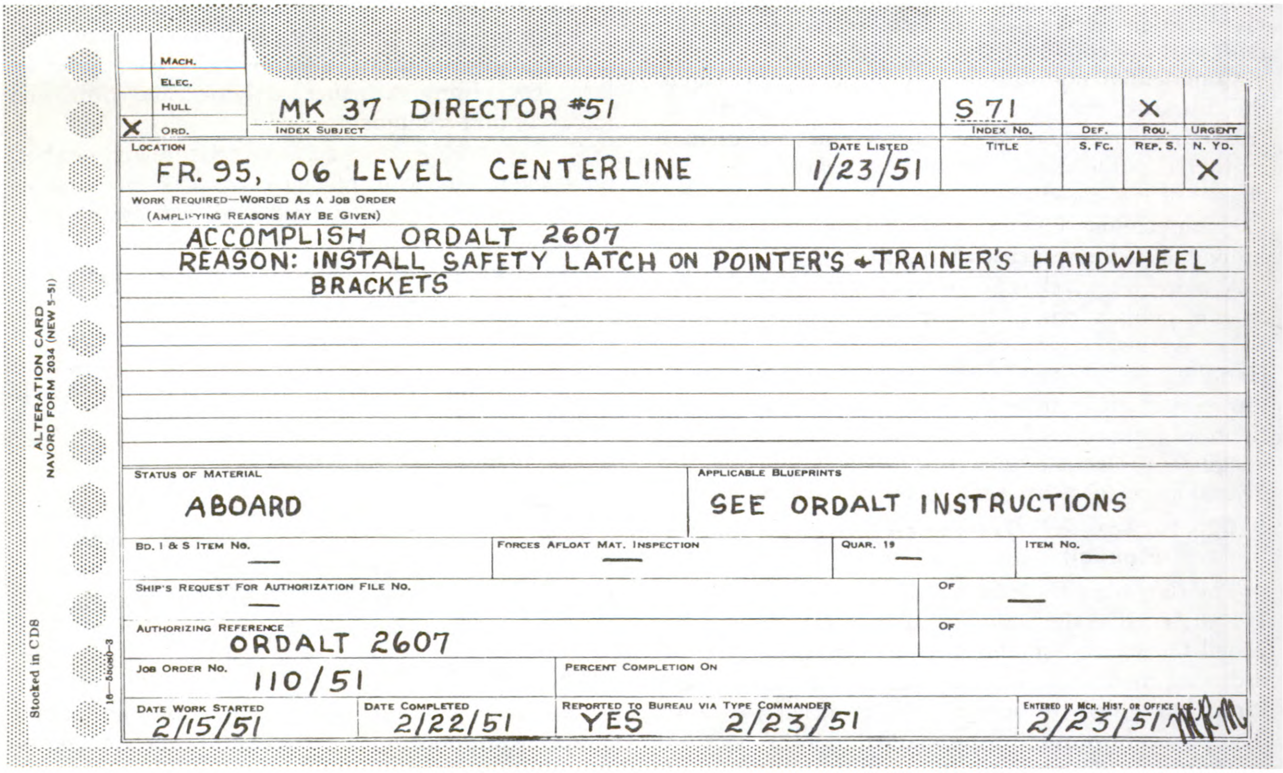
Index Subject: MOUNT 51
Index No.: S 74
Def.:
Rou.:
Urgent: X

Location: FRAME 80-01 LEVEL—CENTERLINE
Date Listed: 4/15/51
Title:
S. Fc.:
Rep. S.:
N. Yd.: X

Work Required—Worded As a Job Order (Amplifying Reasons May Be Given)
REPLACE GUN BARRELS (2); SER NOS 7183, 7184
REASON - WORN OUT; E.S.R. 5100 RDS.

Status of Material: AVAILABLE AT NAVY YARD
Applicable Blueprints:
Bd. I & S Item No.:
Forces Afloat Mat. Inspection:
Quar. 194
Item No.:
Ship's Request for Authorization File No.: 101011 Z
Of: APRIL 1951
Authorizing Reference: COMCRU DESPAC 141925 Z
Of: APRIL 1951
Job Order No.: 123/51
Percent Completion On:
Date Work Started: 12 MAY '51
Man-Hours to Complete: 105
Date Completed: 14 MAY 1951
Entered in Mch. Hist. or Office Log.: 20 MAY 1951

Figure 31B1.—Sample ordnance repair card.



ALTERATION CARD NAVORD FORM 2034 (NEW 5-51)

Stocked in CDS

16—55080-3

Mach.
Elec.
Hull
X Ord.

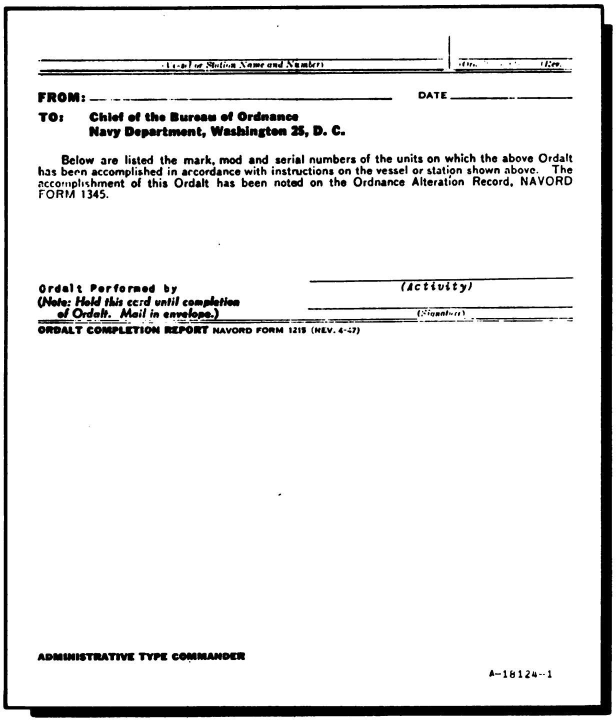
Index Subject: MK 37 DIRECTOR #51
Index No.: S 71
Def.:
Rou.: X
Urgent:

Location: FR. 95, 06 LEVEL CENTERLINE
Date Listed: 1/23/51
Title:
S. Fc.:
Rep. S.:
N. Yd.: X

Work Required—Worded As a Job Order (Amplifying Reasons May Be Given)
ACCOMPLISH ORDALT 2607
REASON: INSTALL SAFETY LATCH ON POINTER'S + TRAINER'S HANDWHEEL BRACKETS

Status of Material: ABOARD
Applicable Blueprints: SEE ORDALT INSTRUCTIONS
Bd. I & S Item No.: —
Forces Afloat Mat. Inspection: —
Quar. 19 —
Item No.: —
Ship's Request for Authorization File No.: —
Of: —
Authorizing Reference: ORDALT 2607
Of:
Job Order No.: 110/51
Percent Completion On:
Date Work Started: 2/15/51
Date Completed: 2/22/51
Reported to Bureau via Type Commander: YES 2/23/51
Entered in Mch. Hist. or Office Log.: 2/23/51

Figure 31B2.—Sample ordnance alteration card.



(Vessel or Station Name and Number) (Or[illegible]) (Rev.

FROM: ______ DATE ______

TO: **Chief of the Bureau of Ordnance**
Navy Department, Washington 25, D. C.

Below are listed the mark, mod and serial numbers of the units on which the above Ordalt has been accomplished in accordance with instructions on the vessel or station shown above. The accomplishment of this Ordalt has been noted on the Ordnance Alteration Record, NAVORD FORM 1345.

Ordalt Performed by ______ *(Activity)*
(Note: Hold this card until completion of Ordalt. Mail in envelope.) ______ (Signature)

ORDALT COMPLETION REPORT NAVORD FORM 1215 (REV. 4-47)

ADMINISTRATIVE TYPE COMMANDER

A-18124-1

Figure 31B3.—Sample ordnance completion card.

Ordnance Pamphlets contain more general instructions or such data as range tables, nomenclature lists, *etc.* Registered Ordnance Pamphlets are issued as ORD______ instead of OP______. Ordnance Pamphlets are numbered serially and are listed both by number and by subject in OP 0, the *Index of Ordnance Publications.* The following nonconfidential Ordnance Pamphlets are of general interest:

OP 4, *Ammunition, Instructions for the Naval Service Afloat.*

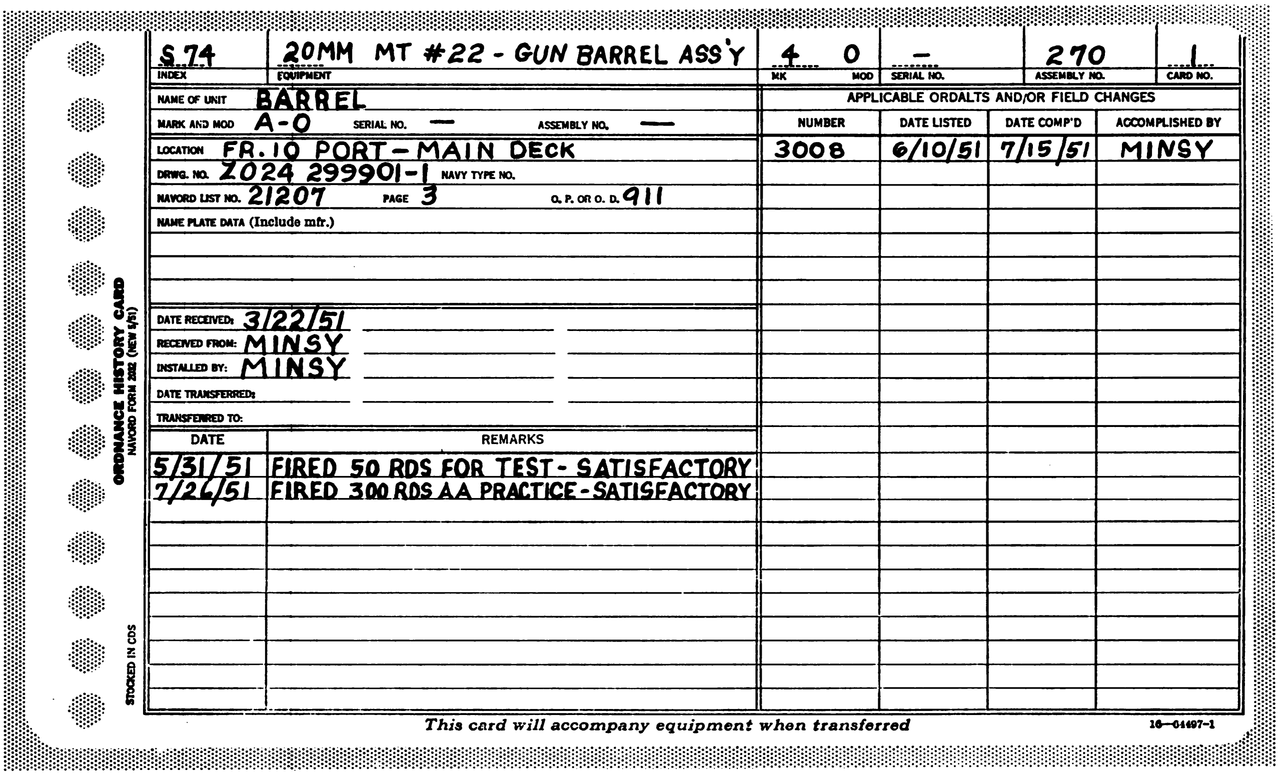
OP 556, *Optical Equipment, the Principles of Stereoscopic Vision.*

OP 599, *Ordnance Drafting Room Regulations.*

OP 762, *Alignment of Ordnance Installations on Board Ship.*

31C5. Allowance lists

When a ship is placed in commission or when new ordnance material is issued to a ship already in commission, an allowance list is prepared and issued to the ship for each group or type of equipment, to cover all the articles which the vessel is supposed to carry. The allowance lists of an individual ship cover ammunition, the main units and subunits of equipment (such as guns, mounts, fire control instruments, etc.) and also the spare parts, accessories, and special tools which are required for the maintenance of this material. The allowance lists show quantities as well as designat-



INDEX	EQUIPMENT	MK	MOD	SERIAL NO.	ASSEMBLY NO.	CARD NO.
S 74	20MM MT #22 - GUN BARREL ASS'Y	4	0	–	270	1

NAME OF UNIT BARREL
MARK AND MOD A-0 SERIAL NO. — ASSEMBLY NO. —
LOCATION FR. 10 PORT – MAIN DECK
DRWG. NO. Z024 299901-1 NAVY TYPE NO.
NAVORD LIST NO. 21207 PAGE 3 O. P. OR O. D. 911
NAME PLATE DATA (Include mfr.)

DATE RECEIVED: 3/22/51
RECEIVED FROM: MINSY
INSTALLED BY: MINSY
DATE TRANSFERRED:
TRANSFERRED TO:

DATE	REMARKS
5/31/51	FIRED 50 RDS FOR TEST - SATISFACTORY
7/26/51	FIRED 300 RDS AA PRACTICE - SATISFACTORY

APPLICABLE ORDALTS AND/OR FIELD CHANGES

NUMBER	DATE LISTED	DATE COMP'D	ACCOMPLISHED BY
3008	6/10/51	7/15/51	MINSY

ORDNANCE HISTORY CARD
NAVORD FORM 2082 (NEW 5/51)

STOCKED IN CDS

This card will accompany equipment when transferred

16—04497-1

Figure 31B4.—Ordnance history card showing typical entries.

ing name, description, and drawing numbers of items. As allowance lists are authority for obtaining the material contained therein, articles contained on the allowance lists but not on board may be requisitioned from supply activities or, in certain cases, from repair ships or other vessels.

31C6. Ordnance drawings and ordnance sketches

Each piece of ordnance material is shown on an *ordnance drawing* or a group of drawings in sufficient detail to permit the manufacture of the article. In addition, ordnance drawings may be prepared to show general arrangements, lubrication instructions, and other design information which, although not necessary for manufacture, is required for operation or upkeep purposes. Ordnance sketches are either *line sketches,* which are used in place of drawings for primary or experimental material, or *list sketches,* which list by number all the drawings pertaining to one unit assembly or type of ordnance material.

Ships in commission are required to carry full sets of the ordnance drawings and list sketches pertaining to the equipment carried on board. In addition, for more ready reference, they are usually provided with reduced-size photoprints of the pertinent drawings.

By reference to the list sketch or drawing for the mark and modification of a given assembly or subassembly, it is possible to trace through the sketch list of drawings for the mark and mod of the basic unit and the individual drawings making up that unit, to identify the correct nomenclature, the drawing and piece number, the design dimensions and tolerances, and all the other information relating to an individual part. Each individual part is identified in allowance lists by its drawing and piece number. Whenever possible, it is also identified by having the drawing and piece number stamped or engraved on the part.

31C7. Other BuOrd publications

Other publications issued by the Bureau of Ordnance include the following:

1. *Ordnance Data* (OD's). These contain information regarding inspection and test data of ordnance equipment. Some OD's contain information of a more general nature. OD's are indexed in OP 0.
2. *Ordnance Specifications* (OS's). These publications provide specifications for manufacturers producing ordnance equipment. Some of the specifications, especially those dealing with lubricants, are of general interest.
3. *Ordnance Standards* (OSTD's). Ordnance standards provide a guide for the standardization of Bureau of Ordnance methods of drafting and manufacture.
4. *Ordnance Alterations* (ORDALTS). Ordnance alterations provide instructions for alterations to installed ordnance equipment. They are described above.

31C8. Publications issued by other than Bureau of Ordnance

Information parallel to that contained in ordnance publications but with respect to items obtained by the Bureau of Ordnance from the United States Army is contained in Army publications which are made available to the Naval service through the same channels as Bureau of Ordnance publications.

Publications which define the tactical employment of ships and armament are usually published by the Chief of Naval Operations. Within past years these have taken the form of a numbered series of United States Fleet Publications (USF's). They treat all the modern concepts of naval warfare, from amphibious assaults to fast carrier task force operations. They deal with the role of each type of ship in all the various phases of naval warfare.

Three new publications series, *Naval Warfare Publications* (NWP's), *Naval Warfare Information Publications* (NWIP's), and *Fleet Exercise Publications* (FXP's) are in the process of being distributed to the Fleet. They are to supersede USF's and provide additional information. NWIP's amplify NWP's by giving procedural and technical details not appropriate in the parent book. FXP's establish a reference and guide for the conduct of fleet and individual ship exercises.

Of more immediate interest to the junior officer are the publications which are issued by Fleet and Type Commanders concerning gunnery doctrine. Gunnery doctrines comprise standard procedures for the most effective control of guns, based on past experience and the capabilities of the particular batteries. The junior officer must know the doctrine for his battery by heart. He must insist that all personnel under him, particularly those in control stations, shall also be completely familiar with provisions of the doctrine.

The *Gunnery Department Organization Book* is compiled by the Ship's Gunnery Officer to provide for the proper administration of his department. It includes the specialized gunnery duties of the officers and leading petty officers of the department, as well as the administrative routine. It is therefore essential that all officers of the Gunnery Department become familiar with this book as soon as possible after reporting on board.

The Bureau of Naval Personnel publishes a series of Navy Training Courses based on the requirements for advancement in rating of enlisted personnel. The junior gunnery officer will find those books relating to ordnance ratings valuable supplements to the technical literature of his profession.

D. Gunnery Exercises

31D1. Objectives of gunnery exercises

Obviously, the most important objective in gunnery exercises is to train personnel to attain the most effective use of the ship's armament. Another important objective is the development of new doctrines, techniques, and procedures to keep pace with new targets and new equipment.

All gunnery exercises are prescribed, scheduled, conducted, and analyzed with the above objectives in view. The conditions under which the exercises are held are made as realistic as possible, in order to eliminate artificialities which might lead to false conclusions.

31D2. Prescribed gunnery exercises

Publications promulgated by CNO prescribe the gunnery exercises now used in the fleet. Separate publications for each type of ship prescribe the training exercises, procedures, and reports required, including outlines of the specific tactical situations which precede the firing.

The publications described in this article are confidential, and as such are in the custody of the Registered Publications Issuing Officer. They, too, may be signed for and drawn for study.

All too frequently reports of gunnery exercises lose their significance as objective analyses and serve merely to represent additional paper work to the junior officer. It must be remembered, however, that it is necessary to make an accurate appraisal of the effectiveness of the ship's armament, and that to do so requires careful, detailed analysis.

Sufficient data must be taken during the exercise to permit post-firing analysis. It must be carefully assembled and even more carefully checked. If the report indicates an ineffective battery, every last detail must be scrutinized until a definite, concrete reason for failure can be found. The maintenance of efficient armament today may well prepare for victory tomorrow.

31D3. Shipboard gunnery files

The junior officer should consult the files of the Gunnery Department aboard his ship for copies of the various types of reports, letters, and requisitions. In these and other pertinent files the officer can see examples of ORDALTS and various other types of work requests, routine and special ordnance reports, and requisitions, as well as reports on gunnery exercises and data concerning the performance of the various batteries.

Frequent reference to the gunnery files will keep the officer posted concerning past gunnery performance as well as current doctrines and procedures. No officer should ever report to a ship feeling that his training is complete, or his knowledge perfect concerning installations and routines. He should be receptive to continued training, and be on the alert to learn not only standard but also improved practices.

31D4. General remarks

Finally, the junior officer should never feel that the complications of modern ordnance and fire control are beyond his abilities of comprehension, or that necessary information for the use and upkeep of equipment is lacking. Every item has something written about it to assist those who must understand its operating principles, use, upkeep, and repair. The publication for a particular item of equipment is probably aboard. If not, it is the duty of the officer concerned to see that the publication is requested, not only for his own requirements, but also for those enlisted personnel who must be informed.

Appendix B

EXTRACTS FROM 8"/55 RANGE TABLE (AND ASSOCIATED EQUIPMENT)

Part 1. Air-Density Nomogram

Align B and T to get point on support D.

Align D with R to get error in yards due to change in density of air.

EXAMPLE:

Given

Barometer	inches	=28.4
Temperature	degrees F	=92
Range	yards	=15000

Result

Error	yards	=+460

NOTE: The best estimate of ballistic density to different altitudes is in very close, but not in exact agreement with standard density when surface conditions are standard. When surface density is not standard, the disagreement is usually greater and is a function of surface density and maximum ordinate. In OP 561–I of May, 1923, pp. 98–114, corrections for density are discussed. Use of figure B-1 will not give agreement with results obtained from column 12 and surface observations only, but should be a more accurate figure, in that it takes into account the ratio between mean measured and standard density for the actual maximum ordinate obtained.

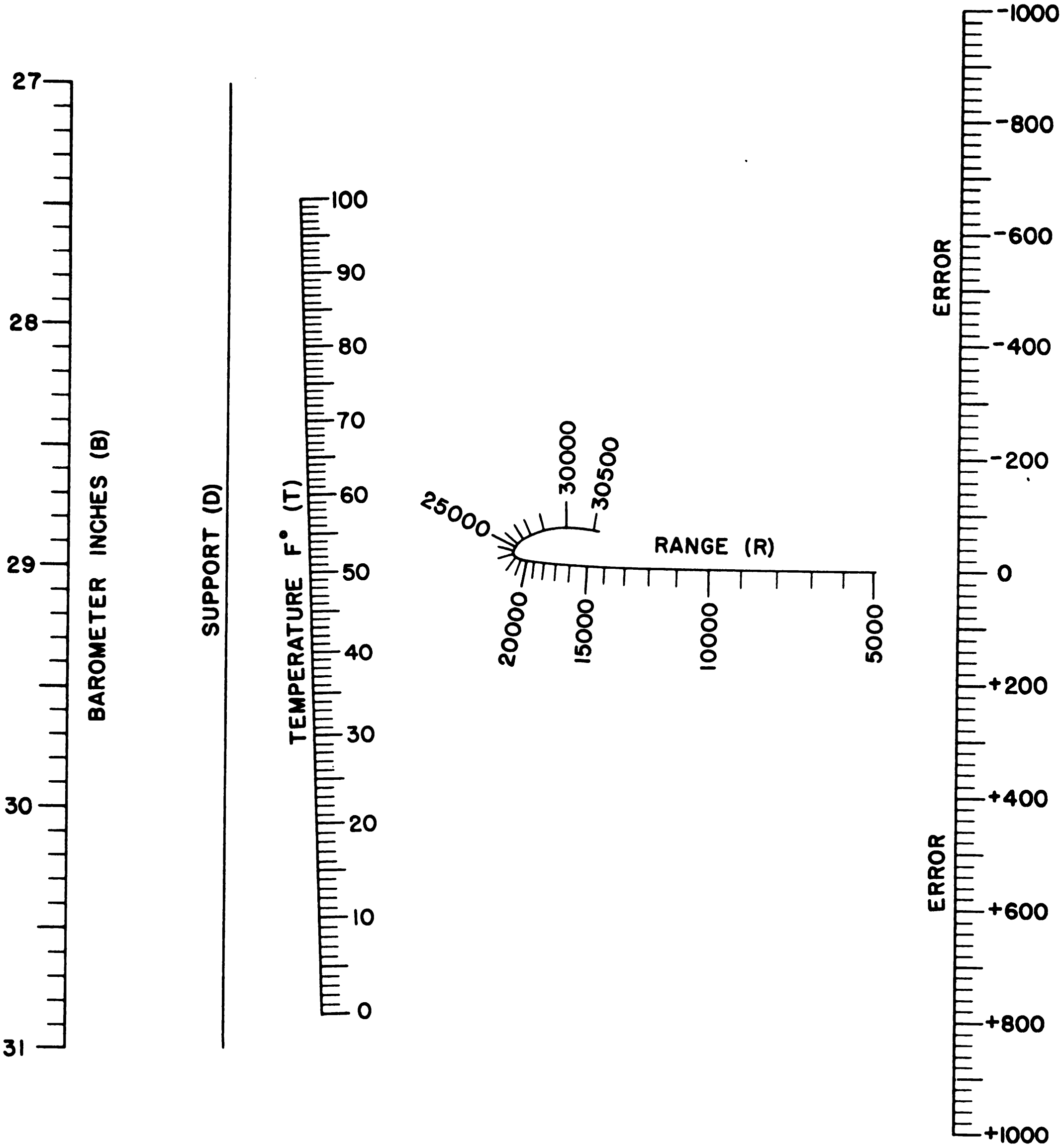


Figure B–1.—Change in range for variation in density of air.

Appendix B, Part 2

EXTRACTS FROM RANGE TABLE FOR 8"/55 GUN

INITIAL VELOCITY = 2500 F. S. WEIGHT OF PROJECTILE = 335 POUNDS. LENGTH OF PROJECTILE = 4.5 CALIBERS. RADIUS OF OGIVE = 9.0 CALIBERS

Range	Angle of elevation		Increase in angle of elevation for 100 yards increase in range	Angle of fall	Time of flight	Striking velocity	Drift	Danger space for a target 20 feet high	Maximum ordinate	
1	2	2a	2b	3	4	5	6	7	8	
Yards	° ′	*Minutes*	*Minutes*	° ′	*Seconds*	*F. S.*	*Yards*	*Yards*	*Feet*	
1000	27.4	27.4	2.8	29	1.23	2412	.2	1000	6	
1100	30.2	30.2	2.8	32	1.35	2403	.2	1100		
1200	33.0	33.0	2.8	35	1.48	2395	.3	1200		
1300	35.8	35.8	2.8	38	1.61	2386	.3	1300		
1400	38.6	38.6	2.8	41	1.73	2377	.4	1400		
1500	41.4	41.4	2.9	44	1.86	2368	.4	1500	14	
1600	44.2	44.2	2.9	47	1.99	2360	.5	1600		
1700	47.2	47.2	2.9	50	2.12	2351	.5	1700		
1800	50.1	50.1	2.9	53	2.24	2342	.6	828		
1900	53.1	53.1	2.9	56	2.37	2334	.6	628		
2000	55.9	55.9	2.9	59	2.50	2325	.7	541	25	
2100	58.8	58.8	2.9	1 02	2.63	2317	.8	487		
2200	1 01.7	61.7	3.0	1 05	2.76	2308	.8	447		
2300	1 04.7	64.7	3.0	1 09	2.89	2300	.9	415		
2400	1 07.7	67.7	3.0	1 12	3.02	2291	1.0	387		
2500	1 10.7	70.7	3.0	1 15	3.15	2283	1.1	363	40	
2600	1 13.7	73.7	3.0	1 18	3.28	2274	1.2	342		
2700	1 16.7	76.7	3.0	1 22	3.41	2266	1.3	323		
2800	1 19.7	79.7	3.0	1 25	3.55	2257	1.4	305		
2900	1 22.7	82.7	3.1	1 28	3.68	2249	1.6	289		
3000	1 25.8	85.8	3.1	1 32	3.81	2240	1.7	275	58	

EXTRACTS FROM RANGE TABLE FOR 8″/55 GUN (Continued)

INITIAL VELOCITY = 2500 F. S. WEIGHT OF PROJECTILE = 335 POUNDS. LENGTH OF PROJECTILE = 4.5 CALIBERS. RADIUS OF OGIVE = 9.0 CALIBERS

	Change of range for variation of +10 feet per second initial velocity 10	Change of range for variation of −5 pounds in weight of projectile 11	Change of range for variation in density of air of −10 per cent 12	Change of range for wind component in plane of fire of 10 knots 13	Change of range for motion of gun in plane of fire of 10 knots 14	Change of range for motion of target in plane of fire of 10 knots 15	Deviation for lateral wind component of 10 knots 16	Deviation for lateral motion of gun perpendicular to line of fire, speed of 10 knots 17	Deviation for lateral motion of target perpendicular to line of fire, speed of 10 knots 18	Change in height of impact for variation of 100 yards in sight bar 19
	Yards	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Feet*
	8	12	2	1	6	7	.2	6.7	6.9	3
	8	13	2	1	7	8	.2	7.4	7.7	3
	9	14	3	1	7	8	.3	8.0	8.4	3
	10	15	3	1	8	9	.3	8.7	9.1	3
	11	16	4	1	9	10	.3	9.4	9.8	4
	11	17	5	1	9	11	.4	10.1	10.5	4
	12	19	5	1	10	11	.4	10.8	11.2	4
	13	20	6	2	10	12	.4	11.4	11.9	4
	14	21	7	2	11	13	.5	12.1	12.7	5
	14	22	8	2	12	13	.5	12.8	13.4	5
	15	23	9	2	12	14	.6	13.5	14.1	5
	16	24	10	2	13	15	.6	14.2	14.8	5
	17	25	11	2	13	16	.7	14.8	15.5	6
	17	26	12	2	14	16	.7	15.5	16.2	6
	18	27	13	2	15	17	.8	16.2	17.0	6
	19	28	14	2	15	18	.9	16.9	17.7	7
	19	29	15	3	16	19	.9	17.6	18.5	7
	20	30	16	3	16	19	1.0	18.2	19.2	7
	21	31	17	3	17	20	1.1	18.9	20.0	7
	22	32	19	3	18	21	1.1	19.6	20.7	8
	22	33	20	3	18	22	1.2	20.3	21.5	8

EXTRACTS FROM RANGE TABLE FOR 8"/55 GUN (Continued)

INITIAL VELOCITY = 2500 F. S. WEIGHT OF PROJECTILE = 335 POUNDS. LENGTH OF PROJECTILE = 4.5 CALIBERS. RADIUS OF OGIVE = 9.0 CALIBERS

Range 1	Angle of elevation 2	2a	Increase in angle of elevation for 100 yards increase in range 2b	Angle of fall 3	Time of flight 4	Striking velocity 5	Drift 6	Danger space for a target 20 feet high 7	Maximum ordinate 8	
Yards	° '	*Minutes*	*Minutes*	° '	*Seconds*	*F. S.*	*Yards*	*Yards*	*Feet*	
9000	5 04.2	304.2	4.3	6 23	12.90	1771	20	60	667	
9100	5 08.5	308.5	4.3	6 29	13.07	1764	20	59		
9200	5 12.8	312.8	4.4	6 36	13.24	1757	21	58		
9300	5 17.2	317.2	4.4	6 42	13.41	1750	21	57		
9400	5 21.6	321.6	4.4	6 49	13.58	1743	22	56		
9500	5 26.0	326.0	4.4	6 56	13.75	1736	22	55	760	
9600	5 30.4	330.4	4.5	7 03	13.93	1729	23	54		
9700	5 34.9	334.9	4.5	7 10	14.11	1722	23	53		
9800	5 39.4	339.4	4.5	7 17	14.29	1715	24	52		
9900	5 43.9	343.9	4.6	7 24	14.47	1708	24	51		
10000	5 48.5	348.5	4.6	7 31	14.65	1702	25	51	862	
10100	5 53.1	353.1	4.6	7 38	14.83	1695	26	50		
10200	5 57.7	357.7	4.6	7 45	15.01	1688	26	49		
10300	6 02.3	362.3	4.7	7 53	15.19	1682	27	48		
10400	6 07.0	367.0	4.7	8 00	15.37	1675	27	47		
10500	6 11.7	371.7	4.7	8 07	15.55	1669	28	47	973	
10600	6 16.4	376.4	4.8	8 15	15.73	1662	29	46		
10700	6 21.2	381.2	4.8	8 22	15.91	1656	29	45		
10800	6 26.0	386.0	4.8	8 30	16.10	1649	30	44		
10900	6 30.8	390.8	4.8	8 37	16.29	1643	31	44		
11000	6 35.6	395.6	4.9	8 45	16.48	1636	31	43	1093	

EXTRACTS FROM RANGE TABLE FOR 8″/55 GUN (Continued)

INITIAL VELOCITY = 2500 F. S. WEIGHT OF PROJECTILE = 335 POUNDS. LENGTH OF PROJECTILE = 4.5 CALIBERS. RADIUS OF OGIVE = 9.0 CALIBERS

	Change of range for variation of +10 feet per second initial velocity 10	**Change of range for variation of −5 pounds in weight of projectile** 11	**Change of range for variation in density of air of −10 per cent** 12	**Change of range for wind component in plane of fire of 10 knots** 13	**Change of range for motion of gun in plane of fire of 10 knots** 14	**Change of range for motion of target in plane of fire of 10 knots** 15	**Deviation for lateral wind component of 10 knots** 16	**Deviation for lateral motion of gun perpendicular to line of fire, speed of 10 knots** 17	**Deviation for lateral motion of target perpendicular to line of fire, speed of 10 knots** 18	**Change in height of impact for variation of 100 yards in sight bar** 19
	Yards	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Feet*
	60	68	188	20	53	73	12	61	73	34
	60	68	192	20	53	74	12	62	74	34
	61	68	196	20	54	75	12	62	75	35
	61	68	200	21	55	76	12	63	76	35
	62	69	204	21	55	77	13	64	77	36
	62	69	208	22	56	78	13	64	78	36
	63	69	212	22	56	79	13	65	79	37
	63	69	217	23	57	80	14	66	80	38
	64	70	221	23	57	81	14	66	81	38
	64	70	225	24	58	82	14	67	82	39
	65	70	230	24	58	83	15	68	83	40
	66	70	234	25	59	84	15	69	84	40
	66	70	239	25	59	85	15	69	85	41
	67	70	243	26	60	86	16	70	86	42
	67	71	248	26	60	87	16	71	87	42
	68	71	252	27	61	88	16	71	88	43
	68	71	257	27	61	89	17	72	89	43
	69	71	262	28	62	90	17	73	90	44
	69	71	266	28	62	91	17	73	91	45
	70	71	271	29	63	92	18	74	92	45
	70	71	276	29	63	93	18	75	93	46

EXTRACTS FROM RANGE TABLE FOR 8"/55 GUN (Continued)

INITIAL VELOCITY = 2500 F. S. WEIGHT OF PROJECTILE = 335 POUNDS. LENGTH OF PROJECTILE = 4.5 CALIBERS. RADIUS OF OGIVE = 9.0 CALIBERS

Range	Angle of elevation		Increase in angle of elevation for 100 yards increase in range	Angle of fall	Time of flight	Striking velocity	Drift	Danger space for a target 20 feet high	Maximum ordinate	
1	2	2a	2b	3	4	5	6	7	8	
Yards	° ′	*Minutes*	*Minutes*	° ′	*Seconds*	*F. S.*	*Yards*	*Yards*	*Feet*	
15000	10 16.6	616.6	6.3	14 57	24.70	1415	70	25	2465	
15100	10 22.9	622.9	6.3	15 08	24.92	1411	71	25		
15200	10 29.2	629.2	6.4	15 19	25.15	1406	73	24		
15300	10 35.6	635.6	6.4	15 30	25.38	1402	74	24		
15400	10 42.0	642.0	6.4	15 41	25.61	1397	75	24		
15500	10 48.4	648.4	6.5	15 52	25.84	1393	77	23	2695	
15600	10 54.9	654.9	6.5	16 03	26.07	1388	78	23		
15700	11 01.4	661.4	6.6	16 15	26.30	1384	80	23		
15800	11 08.0	668.0	6.6	16 27	26.53	1379	81	23		
15900	11 14.6	674.6	6.6	16 39	26.76	1375	82	22		
16000	11 21.2	681.2	6.7	16 51	26.99	1371	84	22	2945	
16100	11 27.9	687.9	6.7	17 03	27.22	1367	85	22		
16200	11 34.6	694.6	6.8	17 15	27.46	1363	87	21		
16300	11 41.4	701.4	6.8	17 27	27.70	1359	88	21		
16400	11 48.2	708.2	6.9	17 39	27.94	1355	90	21		
16500	11 55.1	715.1	6.9	17 51	28.18	1351	92	21	3215	
16600	12 02.0	722.0	7.0	18 03	28.42	1347	93	20		
16700	12 09.0	729.0	7.0	18 15	28.66	1343	95	20		
16800	12 16.0	736.0	7.0	18 27	28.90	1339	96	20		
16900	12 23.0	743.0	7.1	18 40	29.14	1336	98	20		
17000	12 30.1	750.1	7.1	18 53	29.38	1332	100	19	3500	

EXTRACTS FROM RANGE TABLE FOR 8″/55 GUN (Continued)

INITIAL VELOCITY = 2500 F. S. WEIGHT OF PROJECTILE = 335 POUNDS. LENGTH OF PROJECTILE = 4.5 CALIBERS. RADIUS OF OGIVE = 9.0 CALIBERS

	Change of range for variation of +10 feet per second initial velocity 10	Change of range for variation of −5 pounds in weight of projectile 11	Change of range for variation in density of air of −10 per cent 12	Change of range for wind component in plane of fire of 10 knots 13	Change of range for motion of gun in plane of fire of 10 knots 14	Change of range for motion of target in plane of fire of 10 knots 15	Deviation for lateral wind component of 10 knots 16	Deviation for lateral motion of gun perpendicular to line of fire, speed of 10 knots 17	Deviation for lateral motion of target perpendicular to line of fire, speed of 10 knots 18	Change in height of impact for variation of 100 yards in sight bar 19
	Yards	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Feet*
	89	69	495	57	82	139	36	103	139	80
	90	69	501	57	83	140	37	104	140	81
	90	69	507	58	83	141	37	104	141	82
	91	69	513	59	84	142	38	105	142	83
	91	69	519	60	84	144	38	106	144	84
	92	69	525	61	85	145	39	107	145	85
	92	68	531	62	85	146	39	107	146	86
	92	68	537	63	85	148	40	108	148	87
	93	68	543	64	86	149	40	109	149	89
	93	68	550	64	86	150	41	110	150	90
	94	67	556	65	87	152	42	110	152	91
	94	67	562	66	87	153	42	111	153	92
	95	67	568	67	88	154	43	112	154	93
	95	67	575	68	88	156	43	112	156	94
	95	66	581	69	88	157	44	113	157	95
	96	66	587	70	89	158	45	114	158	97
	96	66	593	71	89	160	45	115	160	98
	97	66	600	72	90	161	46	115	161	99
	97	65	606	73	90	162	47	116	162	100
	97	65	612	73	91	164	47	117	164	101
	98	65	619	74	91	165	48	118	165	103

EXTRACTS FROM RANGE TABLE FOR 8"/55 GUN (Continued)

INITIAL VELOCITY = 2500 F. S. WEIGHT OF PROJECTILE = 335 POUNDS. LENGTH OF PROJECTILE = 4.5 CALIBERS. RADIUS OF OGIVE = 9.0 CALIBERS

Range	Angle of elevation		Increase in angle of elevation for 100 yards increase in range	Angle of fall	Time of flight	Striking velocity	Drift	Danger space for a target 20 feet high	Maximum ordinate
1	2	2a	2b	3	4	5	6	7	8
Yards	° '	*Minutes*	*Minutes*	° '	*Seconds*	*F. S.*	*Yards*	*Yards*	*Feet*
19000	15 02.5	902.5	8.2	23 20	34.49	1270	138	15	4840
19100	15 10.7	910.7	8.2	23 34	34.76	1267	140	15	
19200	15 18.9	918.9	8.3	23 48	35.03	1265	142	15	
19300	15 27.2	927.2	8.4	24 03	35.30	1263	145	15	
19400	15 35.6	935.6	8.4	24 17	35.57	1260	147	15	
19500	15 44.0	944.0	8.5	24 31	35.84	1258	149	15	5230
19600	15 52.5	952.5	8.5	24 46	36.11	1256	152	14	
19700	16 01.0	961.0	8.6	25 00	36.38	1254	154	14	
19800	16 09.6	969.6	8.6	25 15	36.66	1252	156	14	
19900	16 18.2	978.2	8.7	25 29	36.94	1250	159	14	
20000	16 26.9	986.9	8.7	25 44	37.22	1248	161	14	5650
20100	16 35.6	995.6	8.8	25 59	37.50	1246	163	14	
20200	16 44.4	1004.4	8.9	26 13	37.78	1244	166	14	
20300	16 53.3	1013.3	8.9	26 28	38.06	1243	168	13	
20400	17 02.2	1022.2	9.0	26 43	38.35	1241	171	13	
20500	17 11.2	1031.2	9.1	26 58	38.64	1240	174	13	6090
20600	17 20.3	1040.3	9.1	27 13	38.93	1238	176	13	
20700	17 29.4	1049.4	9.2	27 28	39.22	1237	179	13	
20800	17 38.6	1058.6	9.3	27 43	39.51	1235	181	13	
20900	17 47.9	1067.9	9.4	27 58	39.80	1234	184	13	
21000	17 57.3	1077.3	9.4	28 13	40.09	1232	187	12	6560

EXTRACTS FROM RANGE TABLE FOR 8″/55 GUN (Continued)

INITIAL VELOCITY = 2500 F. S. WEIGHT OF PROJECTILE = 335 POUNDS. LENGTH OF PROJECTILE = 4.5 CALIBERS. RADIUS OF OGIVE = 9.0 CALIBERS

	Change of range for variation of +10 feet per second initial velocity 10	Change of range for variation of -5 pounds in weight of projectile 11	Change of range for variation in density of air of −10 per cent 12	Change of range for wind component in plane of fire of 10 knots 13	Change of range for motion of gun in plane of fire of 10 knots 14	Change of range for motion of target in plane of fire of 10 knots 15	Deviation for lateral wind component of 10 knots 16	Deviation for lateral motion of gun perpendicular to line of fire, speed of 10 knots 17	Deviation for lateral motion of target perpendicular to line of fire, speed of 10 knots 18	Change in height of impact for variation of 100 yards in sight bar 19
	Yards	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Feet*
	106	59	749	95	99	194	61	133	194	130
	107	59	756	96	100	195	62	134	195	132
	107	58	763	97	100	197	63	134	197	133
	108	58	769	98	100	198	63	135	198	135
	108	58	776	99	101	200	64	136	200	136
	108	57	783	101	101	202	65	137	202	138
	109	57	790	102	102	203	66	138	203	139
	109	57	797	103	102	205	66	138	205	141
	110	56	803	104	102	206	67	139	206	142
	110	56	810	105	103	208	68	140	208	144
	111	56	817	106	103	210	69	141	210	145
	111	55	824	108	104	211	69	142	211	147
	111	55	831	109	104	213	70	143	213	148
	112	54	838	110	105	214	71	143	214	150
	112	54	844	111	105	216	72	144	216	151
	113	54	851	112	105	217	73	145	217	153
	113	53	858	114	106	219	73	146	219	155
	113	53	865	115	106	221	74	147	221	156
	114	53	872	116	107	222	75	147	222	158
	114	52	879	117	107	224	76	148	224	160
	115	52	886	118	107	226	77	149	226	161

EXTRACTS FROM RANGE TABLE FOR 8"/55 GUN (Continued)

INITIAL VELOCITY = 2500 F. S. WEIGHT OF PROJECTILE = 335 POUNDS. LENGTH OF PROJECTILE = 4.5 CALIBERS. RADIUS OF OGIVE = 9.0 CALIBERS

Range	Angle of elevation		Increase in angle of elevation for 100 yards increase in range	Angle of fall	Time of flight	Striking velocity	Drift	Danger space for a target 20 feet high	Maximum ordinate	
1	2	2a	2b	3	4	5	6	7	8	
Yards	° ′	*Minutes*	*Minutes*	° ′	*Seconds*	*F. S.*	*Yards*	*Yards*	*Feet*	
29000	36 01	2161	24	50 33	70.72	1264	582	5	20540	
29100	36 25	2185	24	50 54	71.31	1266	591	5		
29200	36 49	2209	25	51 15	71.92	1269	601	5		
29300	37 14	2234	26	51 36	72.55	1272	612	5		
29400	37 40	2260	27	51 58	73.19	1274	623	5		
29500	38 07	2287	28	52 21	73.86	1277	635	5	22370	
29600	38 35	2315	30	52 44	74.57	1280	647	5		
29700	39 05	2345	31	53 08	75.32	1283	660	5		
29800	39 36	2376	32	53 33	76.10	1286	673	5		
29900	40 08	2408	35	53 59	76.92	1290	688	5		
30000	40 43	2443	39	54 27	77.79	1294	704	5	24770	
30100	41 22	2482	44	54 57	78.73	1298	721	5		
30200	42 06	2526	50	55 29	79.76	1303	740	5		
30300	42 56	2576	60	56 05	80.92	1308	761	4		
30400	43 56	2636	81	56 47	82.26	1315	787	4		
30500	45 17	2717		57 44	84.15	1325	823	4	28880	

EXTRACTS FROM RANGE TABLE FOR 8″/55 GUN (Continued)

INITIAL VELOCITY = 2500 F. S. WEIGHT OF PROJECTILE = 335 POUNDS. LENGTH OF PROJECTILE = 4.5 CALIBERS. RADIUS OF OGIVE = 9.0 CALIBERS

	Change of range for variation of +10 feet per second initial velocity 10	Change of range for variation of −5 pounds in weight of projectile 11	Change of range for variation in density of air of −10 per cent 12	Change of range for wind component in plane of fire of 10 knots 13	Change of range for motion of gun in plane of fire of 10 knots 14	Change of range for motion of target in plane of fire of 10 knots 15	Deviation for lateral wind component of 10 knots 16	Deviation for lateral motion of gun perpendicular to line of fire, speed of 10 knots 17	Deviation for lateral motion of target perpendicular to line of fire, speed of 10 knots 18	Change in height of impact for variation of 100 yards in sight bar 19
	Yards	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Feet*
	151	32	1414	252	146	398	156	242	398	365
	151	32	1419	254	147	401	157	244	401	369
	152	32	1424	257	148	405	159	246	405	374
	152	32	1430	259	149	408	160	248	408	379
	153	32	1435	262	151	412	161	251	412	384
	153	32	1440	264	152	416	163	253	416	389
	154	32	1446	267	153	420	164	256	420	394
	154	32	1451	269	155	424	166	258	424	400
	155	32	1456	272	157	428	167	261	428	406
	155	32	1461	275	159	433	169	264	433	413
	156	32	1466	277	161	438	171	267	438	420
	157	32	1471	280	163	443	172	271	443	428
	157	32	1476	283	166	449	174	275	449	436
	158	32	1480	287	169	456	176	280	456	446
	158	32	1485	291	172	464	178	285	464	458
	159	33	1491	296	178	474	181	293	474	475

EXTRACTS FROM RANGE TABLE FOR 8"/55 GUN (Continued)

I.V. = 2500 F.S.

*EFFECT IN YARDS OF RANGE DUE TO ROTATION OF THE EARTH.

True Target Bearing, Degrees								True Target Bearing, Degrees						
0	15	30	45	60	75	90	Range, Yards	0	15	30	45	60	75	90
180	165	150	135	120	105	90		180	165	150	135	120	105	90
Latitude 0°								Latitude 10° (North or South)						
0	5	10	14	17	19	20	2,000	0	5	10	14	17	19	20
0	14	26	37	46	51	53	6,000	0	13	26	37	45	50	52
0	19	38	53	65	73	75	10,000	0	19	37	52	64	72	74
0	23	45	64	79	88	91	14,000	0	23	45	63	77	86	89
0	26	50	71	87	97	101	18,000	0	26	49	70	86	96	99
0	27	53	75	92	102	106	22,000	0	27	52	74	90	101	104
0	28	53	76	92	103	107	26,000	0	27	53	74	91	102	105
0	23	45	64	78	87	90	30,000	0	23	44	63	77	86	89
Latitude 20° (North or South)								Latitude 30° (North or South)						
0	5	9	13	16	18	19	2,000	0	4	9	12	15	17	17
0	13	25	35	43	48	50	6,000	0	12	23	32	40	44	46
0	18	35	50	61	68	71	10,000	0	17	33	46	56	63	65
0	22	43	60	74	82	85	14,000	0	20	39	56	68	76	79
0	24	47	67	82	91	95	18,000	0	23	44	62	75	84	87
0	26	50	70	86	96	100	22,000	0	24	46	65	79	89	92
0	26	50	71	87	97	100	26,000	0	24	46	65	80	89	92
0	22	42	60	73	82	85	30,000	0	20	39	55	68	75	78
180	195	210	225	240	255	270		180	195	210	225	240	255	270
360	345	330	315	300	285	270		360	345	330	315	300	285	270
True Target Bearing, Degrees								True Target Bearing, Degrees						

*For bearing at top of table the range is increased.

For bearing at bottom of table the range is decreased.

EXTRACTS FROM RANGE TABLE FOR 8"/55 GUN (Continued)

I.V. = 2500 F.S.

*EFFECT IN YARDS OF RANGE DUE TO ROTATION OF THE EARTH.

True Target Bearing, Degrees								True Target Bearing, Degrees						
0 180	15 165	30 150	45 135	60 120	75 105	90 90	Range, Yards	0 180	15 165	30 150	45 135	60 120	75 105	90 90
Latitude 40° (North or South)								Latitude 50° (North or South)						
0	4	8	11	13	15	15	2,000	0	3	6	9	11	12	13
0	10	20	29	35	39	40	6,000	0	9	17	24	29	33	34
0	15	29	41	50	56	58	10,000	0	12	24	34	42	47	48
0	18	35	49	60	67	70	14,000	0	15	29	41	51	56	58
0	20	39	55	67	74	77	18,000	0	17	32	46	56	62	65
0	21	41	57	70	78	81	22,000	0	18	34	48	59	66	68
0	21	41	58	71	79	82	26,000	0	18	34	49	59	66	69
0	18	34	49	60	67	69	30,000	0	15	29	41	50	56	58
Latitude 60° (North or South)								Latitude 70° (North or South)						
0	3	5	7	9	10	10	2,000	0	2	3	5	6	7	7
0	7	13	19	23	25	26	6,000	0	5	9	13	16	17	18
0	10	19	27	33	36	38	10,000	0	7	13	18	23	25	26
0	12	23	32	39	44	45	14,000	0	8	16	22	27	30	31
0	13	25	36	44	49	50	18,000	0	9	17	24	30	33	34
0	14	26	37	46	51	53	22,000	0	9	18	26	31	35	36
0	14	27	38	46	52	53	26,000	0	9	18	26	32	35	37
0	12	23	32	39	43	45	30,000	0	8	15	22	27	30	31
180 360	195 345	210 330	225 315	240 300	255 285	270 270		180 360	195 345	210 330	225 315	240 300	255 285	270 270
True Target Bearing, Degrees								True Target Bearing, Degrees						

*For bearing at top of table the range is increased.

For bearing at bottom of table the range is decreased.

EXTRACTS FROM RANGE TABLE FOR 8"/55 GUN (Continued)

I.V. = 2500 F.S.

*DEFLECTION IN YARDS DUE TO ROTATION OF THE EARTH.

True Target Bearing, Degrees							Range, Yards	True Target Bearing, Degrees						
0	30	60	90	120	150	180		0	30	60	90	120	150	180
360	330	300	270	240	210	180		360	330	300	270	240	210	180
Latitude 0°								Latitude 10°						
0	0	0	0	0	0	0	2,000	0	0	0	0	0	0	0
0	0	0	0	0	0	0	6,000	1	1	1	1	1	1	1
0	0	0	0	0	0	0	10,000	1	1	2	2	2	2	2
-1	-1	-1	0	1	1	1	14,000	3	3	3	4	4	5	5
-3	-3	-2	0	2	3	3	18,000	4	4	5	6	8	9	9
-7	-6	-4	0	4	6	7	22,000	4	4	7	10	14	16	17
-16	-14	-8	0	8	14	16	26,000	1	3	8	16	24	30	32
-42	-37	-21	0	21	37	42	30,000	-16	-10	5	26	47	62	68
Latitude 20°								Latitude 30°						
0	0	0	0	0	0	0	2,000	0	0	0	0	0	0	0
1	1	1	1	1	1	1	6,000	2	2	2	2	2	2	2
3	3	3	3	4	4	4	10,000	5	5	5	5	5	5	5
6	6	7	7	8	8	8	14,000	9	10	10	10	11	11	11
10	10	11	13	14	15	16	18,000	16	16	17	19	20	21	21
14	15	17	21	24	26	27	22,000	24	25	27	30	33	35	36
17	19	25	32	39	45	47	26,000	33	35	40	47	54	59	61
11	17	31	51	71	86	91	30,000	38	43	57	75	93	107	112
180	150	120	90	60	30	0		180	150	120	90	60	30	0
180	210	240	270	300	330	360		180	210	240	270	300	330	360
True Target Bearing, Degrees								True Target Bearing, Degrees						

*Deflections to the right are positive.
Deflections to the left are negative.
Deflections are tabulated for north latitude,
for south latitude use opposite sign.
For north latitude use bearing at top of table.
For south latitude use bearing at bottom of table.

EXTRACTS FROM RANGE TABLE FOR 8"/55 GUN (Continued)

I.V. = 2500 F.S.

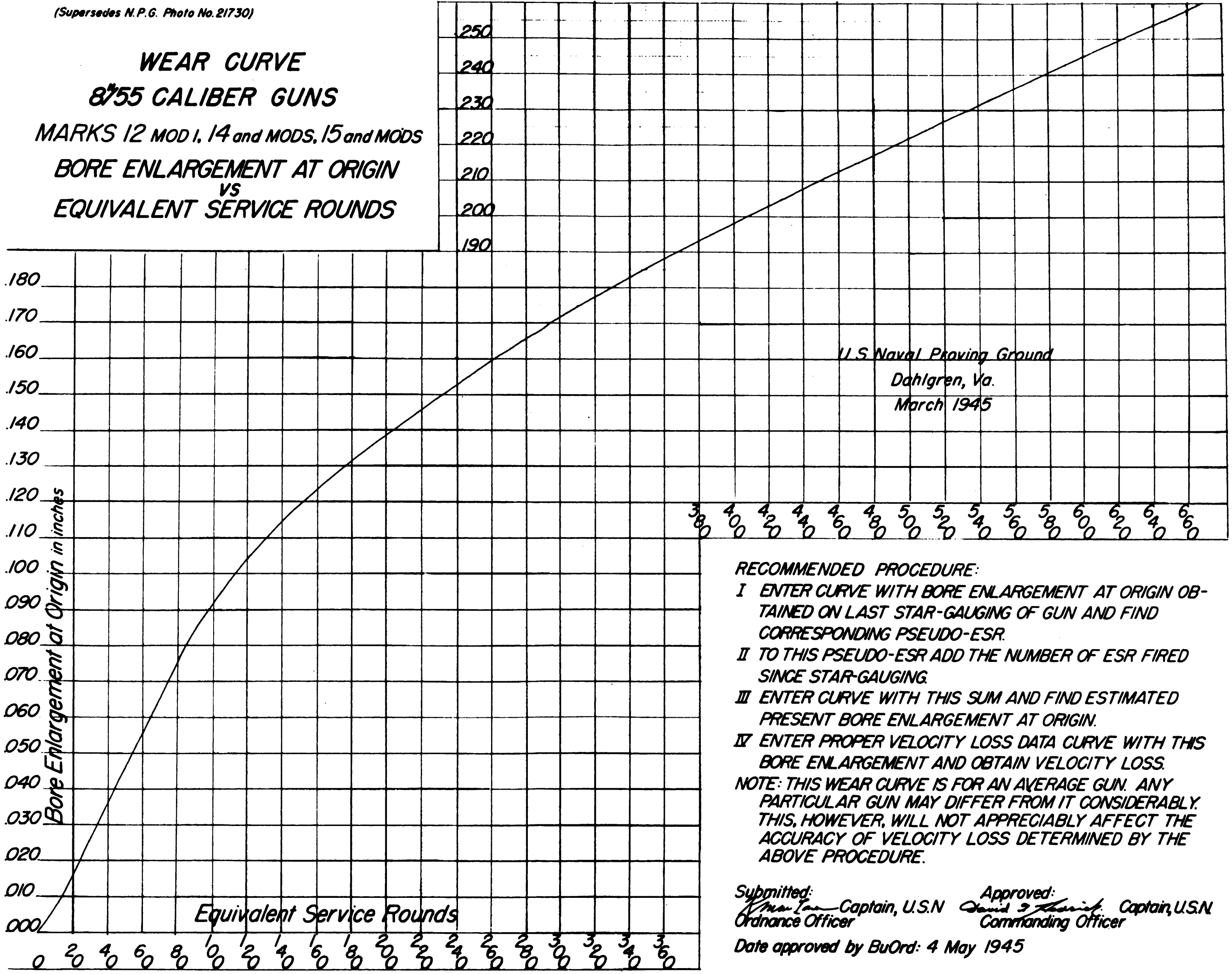
*DEFLECTION IN YARDS DUE TO ROTATION OF THE EARTH.

True Target Bearing, Degrees								True Target Bearing, Degrees						
0 360	30 330	60 300	90 270	120 240	150 210	180 180	Range, Yards	0 360	30 330	60 300	90 270	120 240	150 210	180 180
Latitude 40°								Latitude 50°						
0	0	0	0	0	0	0	2,000	0	0	0	0	0	0	0
2	2	2	2	2	2	2	6,000	3	3	3	3	3	3	3
6	6	6	6	7	7	7	10,000	7	7	8	8	8	8	8
13	13	13	13	14	14	14	14,000	15	15	16	16	16	17	17
22	22	23	24	25	26	26	18,000	27	27	28	29	29	30	30
33	34	36	39	42	43	44	22,000	42	42	44	46	49	50	51
48	50	54	60	66	71	72	26,000	61	63	67	72	77	81	82
64	68	80	96	113	124	129	30,000	88	91	101	115	128	138	142
Latitude 60°								Latitude 70°						
0	0	0	0	0	0	0	2,000	0	0	0	0	0	0	0
3	3	3	3	3	3	3	6,000	3	3	3	3	3	3	3
8	9	9	9	9	9	9	10,000	9	9	9	9	9	10	10
18	18	18	18	18	19	19	14,000	19	19	19	20	20	20	20
31	31	31	32	33	34	34	18,000	34	34	34	35	35	36	36
49	49	51	52	54	55	56	22,000	54	55	56	57	58	59	59
73	74	77	81	85	88	89	26,000	83	83	85	88	91	93	93
109	111	119	130	140	148	151	30,000	126	128	134	141	148	153	155
180 180	150 210	120 240	90 270	60 300	30 330	0 360		180 180	150 210	120 240	90 270	60 300	30 330	0 360
True Target Bearing, Degrees								True Target Bearing, Degrees						

*Deflections to the right are positive.
Deflections to the left are negative.
Deflections are tabulated for north latitude,
for south latitude use opposite sign.
For north latitude use bearing at top of table.
For south latitude use bearing at bottom of table.

Appendix B, Part 3

VELOCITY-LOSS DATA CURVES



N.P.G. Photo No. 29900
(Supersedes N.P.G. Photo No. 21730)

WEAR CURVE
8"/55 CALIBER GUNS
MARKS 12 MOD 1, 14 and MODS, 15 and MODS
BORE ENLARGEMENT AT ORIGIN
VS
EQUIVALENT SERVICE ROUNDS

U.S. Naval Proving Ground
Dahlgren, Va.
March 1945

RECOMMENDED PROCEDURE:

I ENTER CURVE WITH BORE ENLARGEMENT AT ORIGIN OBTAINED ON LAST STAR-GAUGING OF GUN AND FIND CORRESPONDING PSEUDO-ESR.

II TO THIS PSEUDO-ESR ADD THE NUMBER OF ESR FIRED SINCE STAR-GAUGING.

III ENTER CURVE WITH THIS SUM AND FIND ESTIMATED PRESENT BORE ENLARGEMENT AT ORIGIN.

IV ENTER PROPER VELOCITY LOSS DATA CURVE WITH THIS BORE ENLARGEMENT AND OBTAIN VELOCITY LOSS.

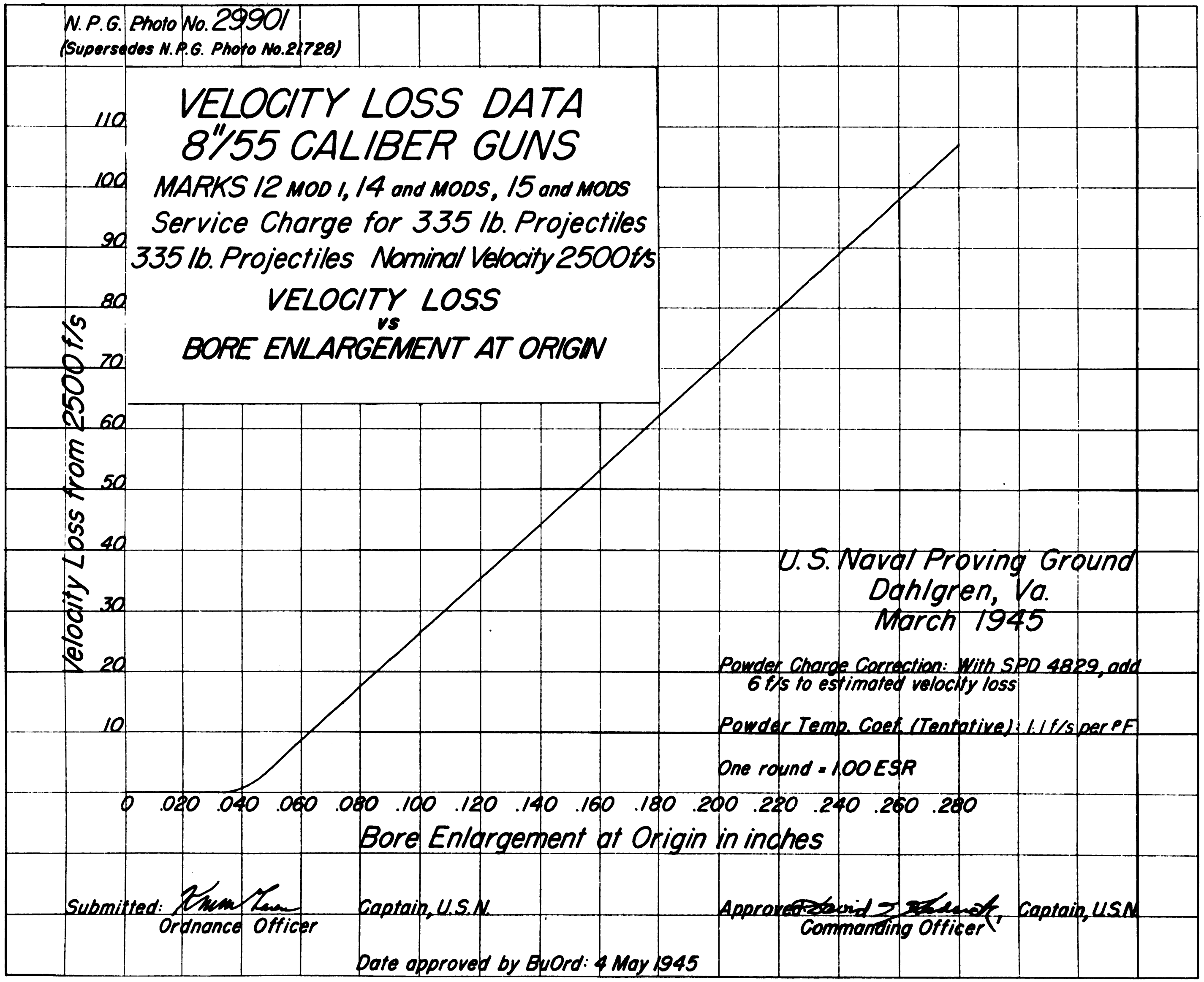
NOTE: THIS WEAR CURVE IS FOR AN AVERAGE GUN. ANY PARTICULAR GUN MAY DIFFER FROM IT CONSIDERABLY. THIS, HOWEVER, WILL NOT APPRECIABLY AFFECT THE ACCURACY OF VELOCITY LOSS DETERMINED BY THE ABOVE PROCEDURE.

Submitted: Captain, U.S.N.
Ordnance Officer

Approved: Captain, U.S.N.
Commanding Officer

Date approved by BuOrd: 4 May 1945

VELOCITY-LOSS DATA CURVES (Continued)



Appendix B, Part 4

WEAR TABLE (TENTATIVE)

8"/55 CALIBER GUNS MK16 MOD 0

INSTRUCTIONS FOR OBTAINING BEST ESTIMATE OF BORE ENLARGEMENT AT ORIGIN.

Definition: The Pseudo-ESR of a gun at any time depends upon two things only, (a.) the actual bore enlargement at origin of the gun at that time, and (b.) the Wear Curve (or it's equivalent, the Wear Table) which applies to that gun. Pseudo-ESR is defined as the value of the ESR on the Wear Curve (or Wear Table) which corresponds to the actual bore enlargement at origin of the gun. Example: If an 8"/55 caliber Mk. 16-0 gun has a bore enlargement of 0".125, its Pseudo-ESR, as read from table at right, is 357.

1. Enter table with bore enlargement at origin obtained on most recent star-gauging of gun, and find its corresponding Pseudo ESR.

2. To this Pseudo ESR add the number of ESR fired since most recent star-gauging of gun.* This will give the best estimate of present Pseudo ESR.

3. Enter table with this estimated present Pseudo ESR and find estimated present bore enlargement at origin.

Example: Given a gun whose present ESR is 484. It was most recently star-gauged when its ESR was 377, and found to have bore enlargement at the origin of 0.125 inches.

1. Entering table with bore enlargement of 0".125, we find that the Pseudo ESR at time of most recent star-gauging was 357.

2. 107 ESR have been fired since most recent star-gauging, hence the estimated present Pseudo ESR is 357 + 107 = 464.

3. Entering the table with this estimated present Pseudo ESR (464) we obtain 0".163 for our best estimate of present bore enlargement at origin.

* ESR should be computed in accordance with the factors listed on this sheet.

BORE ENLARGEMENT AT ORIGIN
(IN THOUSANDTHS OF AN INCH)
VS. EQUIVALENT SERVICE ROUNDS

ESR	0	10	20	30	40	50	60	70	80	90
0	0	0	0	1	1	2	3	4	6	9
100	12	15	18	22	27	32	37	42	48	53
200	59	64	69	74	79	83	87	91	95	99
300	103	107	111	115	119	123	126	130	134	137
400	141	144	148	151	155	158	162	165	168	172
500	175	178	182	185	188	191	194	197	200	203
600	206	209	212	215	218	221	224	227	230	233
700	236	238	241	244	247	249	252	255	257	260
800	263	265	268	270	273	276	278	281	283	286
900	288	290	293	295	298	300	302	305	307	310
1000	312	314	316	319	321	323	325	328	330	332
1100	334	336	339	341	343	345	347	349	351	353
1200	356	358	360	362	364	366	368	370	372	374

ESR Factors
(Tentative)

		Full Charge		Reduced Charge
		SPD Indexes	SPCG Indexes	SPDN or SPDF Indexes
260 lb. Projectiles	Slow Fire	0.68	0.34	0.13
	Rapid Fire †	1.36	0.68	0.26
335 lb. Projectiles	Slow Fire	1.00	0.50	0.15
	Rapid Fire †	2.00	1.00	0.30

† More than 5 rounds per minute

Submitted: C.H. Anderson Captain, U.S.N.
Ordnance Officer

Approved: ______ Rear Admiral, U.S.N.
Commander, Naval Proving Ground

Date Approved by BuOrd: ______

U. S. Naval Proving Ground
Dahlgren, Va.
November 1949

Appendix B, Part 5

VELOCITY-LOSS TABLES

VELOCITY LOSS vs BORE ENLARGEMENT DATA (Tentative)
8"/55 CALIBER GUNS MK.16 MOD.0

335 LB. PROJECTILES
FULL CHARGE - SPD OR SPCG POWDER INDEXES
NOMINAL VELOCITY 2500 f/s

INSTRUCTIONS:

1. Enter table at right with estimated present bore enlargement (as found from current wear table) and obtain velocity loss due to gun erosion.
2. Determine velocity loss due to powder temperature; for these conditions it is 1.3(90°-T) where T is temperature of powder in °F.
3. Add algebraically the two velocity losses above to obtain total velocity loss.

EXAMPLE: Given a gun with 0".163 bore enlargement, a 335 lb. projectile, and a full charge of SPCG 9576 at 72°F.

1. Velocity loss due to gun erosion is 56 f/s
2. Velocity loss due to powder temperature is 1.3(90-72) = 23 f/s
3. Total velocity loss from 2500 f/s is 79 f/s

Powder Temperature Coefficient (Tentative): 1.3 f/s per °F.

E.S.R. Factors (Tentative)	SPD Indexes	SPCG Indexes
Slow Fire	1.0	0.5
Rapid Fire - over 5 R.P.M.	2.0	1.0

Submitted: Captain, U.S.N.
Ordnance Officer

Approved: C. T. Joy Rear Admiral, U.S.N.
Commander Naval Proving Ground

Date Approved by BUORD:

U.S. NAVAL PROVING GROUND
DAHLGREN, VA.
MAY 1949

VELOCITY LOSS FROM 2500 f/s
VS
BORE ENLARGEMENT AT ORIGIN
(in thousandths of an inch)

Bore Enlargement	0	1	2	3	4	5	6	7	8	9
0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0
20	0	1	1	1	2	2	2	3	3	3
30	4	4	4	5	5	6	6	6	7	7
40	8	8	8	9	9	10	10	10	11	11
50	12	12	12	13	13	13	14	14	15	15
60	15	16	16	17	17	17	18	18	19	19
70	19	20	20	20	21	21	22	22	22	23
80	23	24	24	24	25	25	26	26	26	27
90	27	27	28	28	29	29	29	30	30	31
100	31	31	32	32	33	33	33	34	34	35
110	35	35	36	36	36	37	37	38	38	38
120	39	39	40	40	40	41	41	42	42	42
130	43	43	43	44	44	45	45	45	46	46
140	47	47	47	48	48	49	49	49	50	50
150	51	51	51	52	52	52	53	53	54	54
160	54	55	55	56	56	56	57	57	58	58
170	58	59	59	59	60	60	61	61	61	62
180	62	63	63	63	64	64	65	65	65	66
190	66	66	67	67	68	68	68	69	69	70
200	70	70	71	71	72	72	72	73	73	74
210	74	74	75	75	75	76	76	77	77	77
220	78	78	79	79	79	80	80	81	81	81
230	82	82	82	83	83	84	84	84	85	85
240	86	86	86	87	87	88	88	88	89	89
250	90	90	90	91	91	91	92	92	93	93
260	93	94	94	95	95	95	96	96	97	97
270	97	98	98	98	99	99	100	100	100	101
280	101	102	102	102	103	103	104	104	104	105
290	105	105	106	106	107	107	107	108	108	109

NOTE: In general, expected velocity loss should be determined both from bore enlargement and erosion gauge data, and the results averaged. However, the erosion gauge data are preferred if more than 150 E.S.R. have been fired since most recent star-gauging.

VELOCITY-LOSS TABLES (Continued)

VELOCITY LOSS vs EROSION GAUGE DATA (Tentative)

8"/55 CALIBER GUNS MK.16 MOD.0

335 LB. PROJECTILES
FULL CHARGE-SPD OR SPCG POWDER INDEXES
NOMINAL VELOCITY 2500 f/s

INSTRUCTIONS:

1. Enter table at right with present erosion gauge reading and obtain velocity loss due to gun erosion.
2. Determine velocity loss due to powder temperature; for these conditions it is 1.3(90°-T) where T is temperature of powder in °F.
3. Add algebraically the two velocity losses above to obtain total velocity loss.

EXAMPLE: Given a gun with erosion gauge reading 52".4, a 335 lb. projectile, and a full charge of SPCG 9576 at 72°F.

1. Velocity loss due to gun erosion is 72 f/s
2. Velocity loss due to powder temperature is 1.3(90-72) = 23 f/s
3. Total velocity loss from 2500 f/s is 95 f/s

Powder Temperature Coefficient (Tentative): 1.3 f/s per °F.

E.S.R. Factors (Tentative)	SPD Indexes	SPCG Indexes
Slow Fire	1.0	0.5
Rapid Fire - over 5 R.P.M.	2.0	1.0

Submitted: Captain, U.S.N.
Ordnance Officer
Approved: C. T. Joy Rear Admiral, U.S.N.
Commander Naval Proving Ground
Date Approved by BUORD:

U.S. NAVAL PROVING GROUND
DAHLGREN, VA.
MAY 1949

VELOCITY LOSS FROM 2500 f/s
vs
EROSION GAUGE READING *
(8" Bore Erosion Gauge Mk.2 Mod.0)

Erosion Gauge Reading	0	1	2	3	4	5	6	7	8	9
30.0	0	0	0	0	0	0	0	0	0	0
31.0	1	1	2	2	3	4	4	5	5	6
32.0	7	7	8	8	9	10	10	11	11	12
33.0	12	13	13	14	14	15	15	16	16	16
34.0	17	17	18	18	18	19	19	19	20	20
35.0	20	20	21	21	21	22	22	22	23	23
36.0	23	23	24	24	24	25	25	25	25	26
37.0	26	26	27	27	27	28	28	28	28	29
38.0	29	29	30	30	30	31	31	31	31	32
39.0	32	32	33	33	33	33	34	34	34	35
40.0	35	35	36	36	36	36	37	37	37	38
41.0	38	38	38	39	39	39	40	40	40	41
42.0	41	41	41	42	42	42	43	43	43	44
43.0	44	44	44	45	45	45	46	46	46	46
44.0	47	47	47	48	48	48	49	49	49	49
45.0	50	50	50	51	51	51	51	52	52	52
46.0	53	53	53	54	54	54	54	55	55	55
47.0	56	56	56	57	57	57	57	58	58	58
48.0	59	59	59	59	60	60	60	61	61	61
49.0	62	62	62	62	63	63	63	64	64	64
50.0	64	65	65	65	66	66	66	67	67	67
51.0	67	68	68	68	69	69	69	69	70	70
52.0	70	71	71	71	72	72	72	72	73	73
53.0	73	74	74	74	75	75	75	75	76	76
54.0	76	77	77	77	77	78	78	78	79	79
55.0	79	80	80	80	80	81	81	81	82	82
56.0	82	82	83	83	83	84	84	84	85	85
57.0	85	85	86	86	86	87	87	87	88	88
58.0	88	88	89	89	89	90	90	90	90	91
59.0	91	91	92	92	92	93	93	93	93	94
60.0	94	94	95	95	95	95	96	96	96	97
61.0	97	97	98	98	98	98	99	99	99	100
62.0	100	100	101	101	101	101	102	102	102	103
63.0	103	103	103	104	104	104	105	105	105	106
64.0	106	106	106	107	107	107	108	108	108	108

*Reading taken at housing face (actually 6".45 aft of deflector face), gun in 8" housing Mk.1 Mods. 0,1. If reading is taken at breech face (actually 6".25 aft) add 28".7 to obtain corresponding reading at housing face.

Appendix B, Part 6

BALLISTIC PROBLEMS, 8″/55 GUN

Gun Ballistic Correction in Range (True Wind)

The errors in range are:		*Over*	*Short*
1. Powder temp.	Col. 10: $\frac{20}{10}\times 65=$	X	130
2. Erosion loss	Col. 10: $\frac{18}{10}\times 65=$	X	117
3. Air density	Col. 12: (M)0.43×230	X	99
4. Target in LOS	Col. 15: $\frac{35}{10}\times 83$	29	X
5. Wind in LOS	Col. 13: $\frac{71}{10}\times 24$	X	17
6. Gun in LOS	Col. 14: $\frac{9.0}{10}\times 58$	52	X
7. Sum		81	363
		Drop	Add
8. Computed gun ballistic correction in range (yards)		X	282

Gun Ballistic Correction in Deflection (True Wind)

The errors in deflection are:		*Right*	*Left*
1. Drift	Col. 6	25	X
2. Target across LOS	Col. 18: $\frac{19.7}{10}\times 83=$	X	164
3. Wind across LOS	Col. 16: $\frac{71}{10}\times 15=$	11	X
4. Gun across LOS	Col. 17: $\frac{15.6}{10}\times 68=$	106	X
5. Sum		142	164
		Left	Right
6. Computed gun ballistic correction in deflection (yards)		X	22

BALLISTIC PROBLEMS, 8"/55 GUN (Continued)

Correction in Range for Own-Ship Motion

(True Wind)

The errors in range are:			*Over*	*Short*
LOS 1. T ↓ Over 10	4. Target in LOS	Col. 15	83	X
	5. Wind in LOS	Col. 13	X	X
	6. Gun in LOS	Col. 14	58	X
2. W Zero	7. Sum		141	X
			Drop	Add
3. O ↑ Over 10	8. Computed gun ballistic correction in range		141	X

Correction in Range for Own-Ship Motion

(Apparent Wind)

The errors in range are:			*Over*	*Short*
LOS 1. T ↓ Over 10	4. Target in LOS	Col. 15	83	X
	5. Wind in LOS	Col. 13	X	24
	6. Gun in LOS	Col. 15	83	X
2. W ↓ Short 10	7. Sum		166	24
			Drop	Add
3. O ↑ Over 10	8. Computed gun ballistic correction in range		142	X

BALLISTIC PROBLEMS, 8"/55 GUN (Continued)

Gun Ballistic Correction in Range

(Apparent Wind)

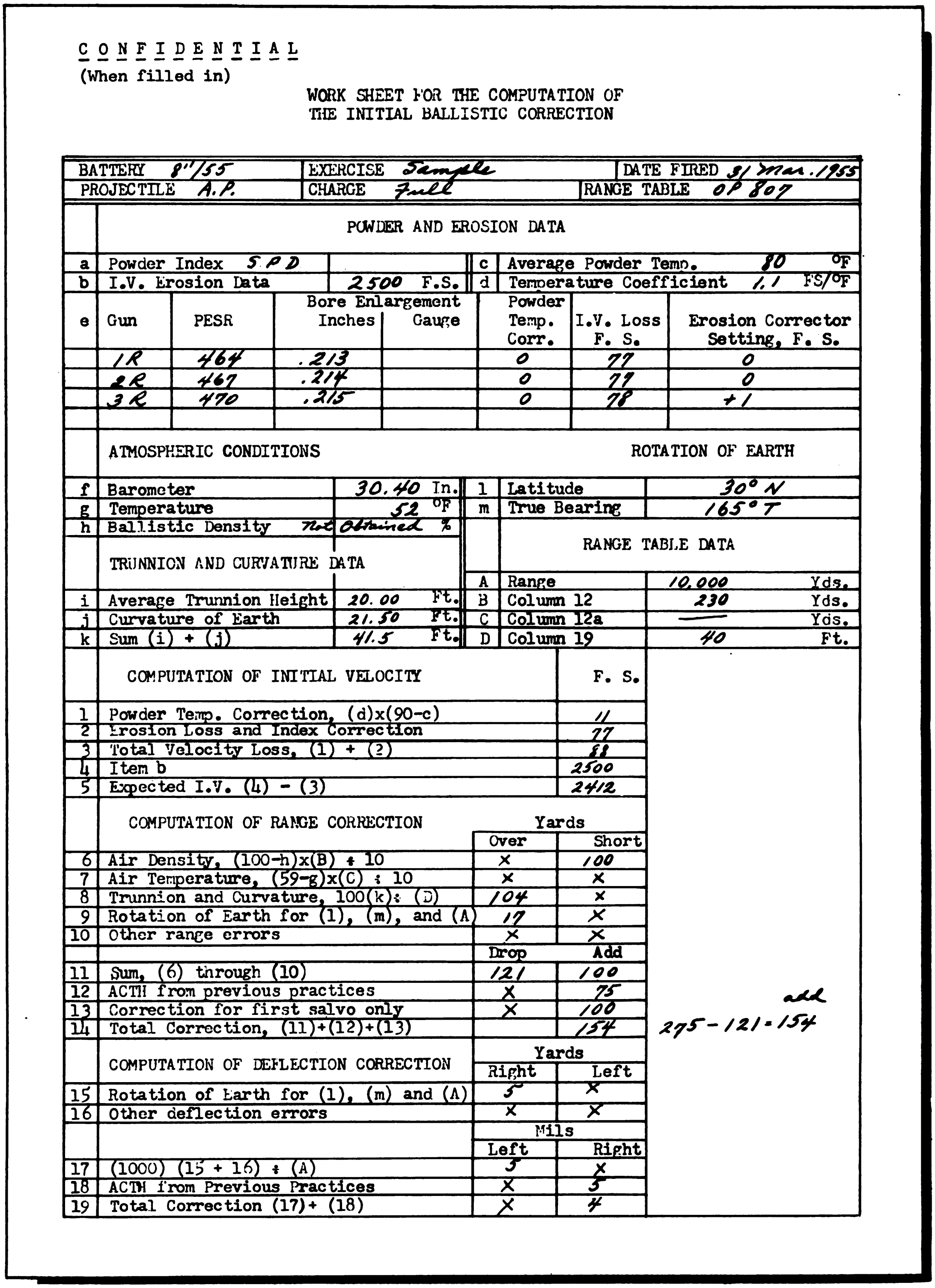
The errors in range are:	*Over*	*Short*
1. Powder temp. (article 17C3)	X	130
2. Erosion loss (article 17C3)	X	117
3. Air density (article 17C3)	X	99
4. Wind Col. 13: $\frac{16.1}{10}\times 24=$	X	39
5. Gun and target Col. 15: $\frac{12.5}{10}\times 83=$	104	X
6. Sum	104	385
	Drop	Add
7. Computed gun ballistic correction in range	X	281

Gun Ballistic Correction in Reflection

(Apparent Wind)

The errors in deflection are:	*Right*	*Left*
1. Drift	25	X
2. Wind Col. 16: $\frac{85}{10}\times 15=$	X	13
3. Gun and target Col. 18: $\frac{4.1}{10}\times 83=$	X	34
4. Sum	25	47
	Left	Right
5. Computed gun ballistic correction in deflection	X	22

BALLISTIC PROBLEMS 8"/55 GUN (Continued)



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WORK SHEET FOR THE COMPUTATION OF
THE INITIAL BALLISTIC CORRECTION

BATTERY 8"/55	EXERCISE Sample	DATE FIRED 31 Mar. 1955
PROJECTILE A.P.	CHARGE Full	RANGE TABLE OP 807

POWDER AND EROSION DATA

a	Powder Index SPD			c	Average Powder Temp.	80 °F
b	I.V. Erosion Data	2500 F.S.		d	Temperature Coefficient	1.1 FS/°F

e	Gun	PESR	Bore Enlargement Inches	Bore Enlargement Gauge	Powder Temp. Corr.	I.V. Loss F. S.	Erosion Corrector Setting, F. S.
	1R	464	.213		0	77	0
	2R	467	.214		0	77	0
	3R	470	.215		0	78	+1

ATMOSPHERIC CONDITIONS — ROTATION OF EARTH

f	Barometer	30.40 In.	l	Latitude	30° N
g	Temperature	52 °F	m	True Bearing	165° T
h	Ballistic Density	Not Obtained %			

TRUNNION AND CURVATURE DATA

i	Average Trunnion Height	20.00 Ft.
j	Curvature of Earth	21.50 Ft.
k	Sum (i) + (j)	41.5 Ft.

RANGE TABLE DATA

A	Range	10,000 Yds.
B	Column 12	230 Yds.
C	Column 12a	— Yds.
D	Column 19	40 Ft.

	COMPUTATION OF INITIAL VELOCITY	F. S.
1	Powder Temp. Correction, (d)x(90-c)	11
2	Erosion Loss and Index Correction	77
3	Total Velocity Loss, (1) + (2)	88
4	Item b	2500
5	Expected I.V. (4) - (3)	2412

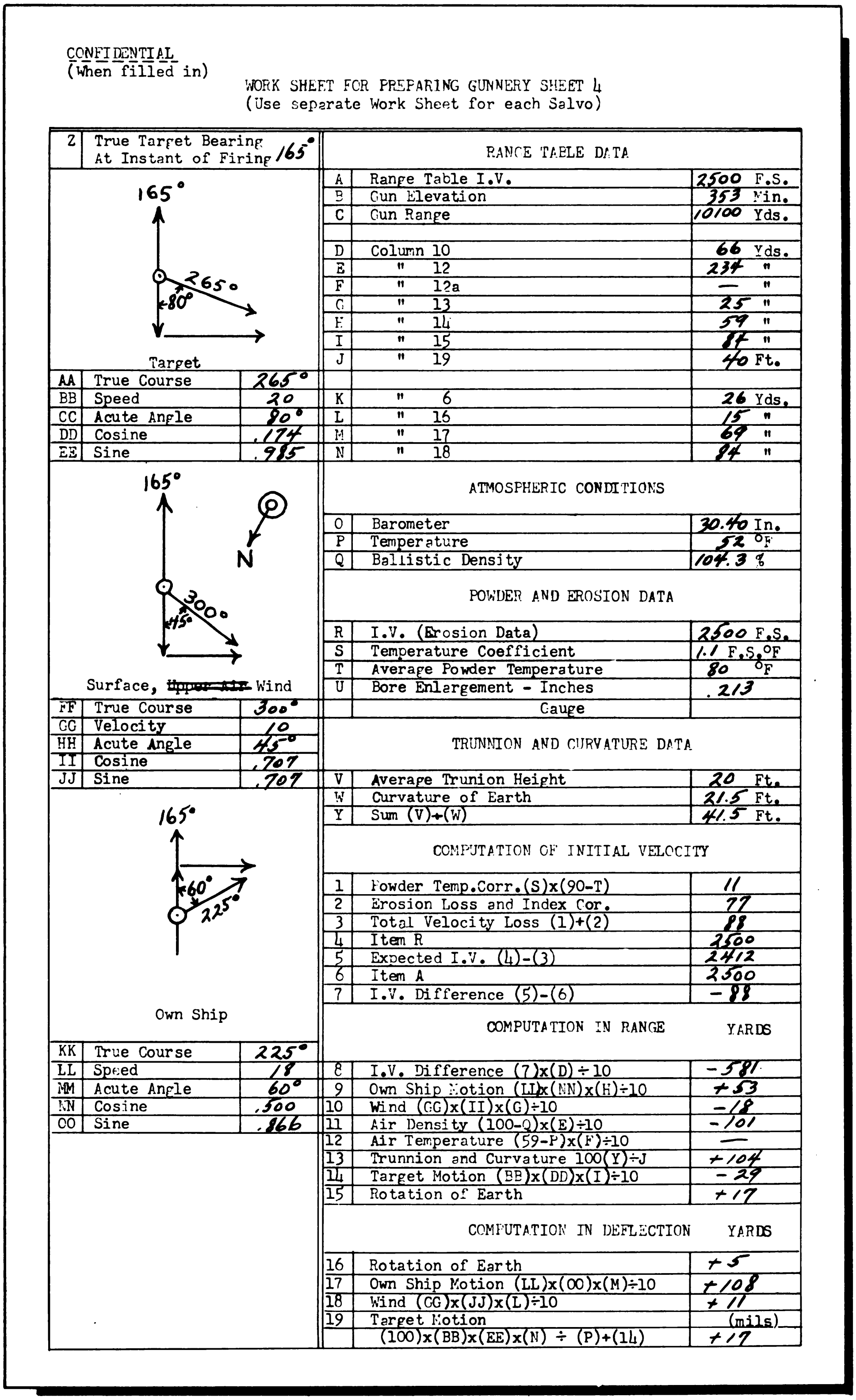
	COMPUTATION OF RANGE CORRECTION	Yards	
		Over	Short
6	Air Density, (100-h)x(B) ÷ 10	x	100
7	Air Temperature, (59-g)x(C) ÷ 10	x	x
8	Trunnion and Curvature, 100(k) ÷ (D)	104	x
9	Rotation of Earth for (l), (m), and (A)	17	x
10	Other range errors	x	x
		Drop	Add
11	Sum, (6) through (10)	121	100
12	ACTH from previous practices	x	75
13	Correction for first salvo only	x	100
14	Total Correction, (11)+(12)+(13)		154

add
275 - 121 = 154

	COMPUTATION OF DEFLECTION CORRECTION	Yards	
		Right	Left
15	Rotation of Earth for (l), (m) and (A)	5	x
16	Other deflection errors	x	x
		Mils	
		Left	Right
17	(1000) (15 + 16) ÷ (A)	5	x
18	ACTH from Previous Practices	x	5
19	Total Correction (17) + (18)	x	4

Figure B2.—Work sheet for computation of initial ballistic correction (8-inch).

BALLISTIC PROBLEMS 8"/55 GUN (Continued)


165°
265°
80°
165°
N
300°
45°
165°
60°
225°

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WORK SHEET FOR PREPARING GUNNERY SHEET 4
(Use separate Work Sheet for each Salvo)

Z	True Target Bearing At Instant of Firing	165°

Target

AA	True Course	265°
BB	Speed	20
CC	Acute Angle	80°
DD	Cosine	.174
EE	Sine	.985

Surface, ~~Upper Air~~ Wind

FF	True Course	300°
GG	Velocity	10
HH	Acute Angle	45°
II	Cosine	.707
JJ	Sine	.707

Own Ship

KK	True Course	225°
LL	Speed	18
MM	Acute Angle	60°
NN	Cosine	.500
OO	Sine	.866

RANGE TABLE DATA

A	Range Table I.V.	2500 F.S.
B	Gun Elevation	353 Min.
C	Gun Range	10100 Yds.
D	Column 10	66 Yds.
E	" 12	234 "
F	" 12a	— "
G	" 13	25 "
H	" 14	59 "
I	" 15	87 "
J	" 19	40 Ft.
K	" 6	26 Yds.
L	" 16	15 "
M	" 17	69 "
N	" 18	84 "

ATMOSPHERIC CONDITIONS

O	Barometer	30.40 In.
P	Temperature	52 °F
Q	Ballistic Density	104.3 %

POWDER AND EROSION DATA

R	I.V. (Erosion Data)	2500 F.S.
S	Temperature Coefficient	1.1 F.S.°F
T	Average Powder Temperature	80 °F
U	Bore Enlargement - Inches Gauge	.213

TRUNNION AND CURVATURE DATA

V	Average Trunion Height	20 Ft.
W	Curvature of Earth	21.5 Ft.
Y	Sum (V)+(W)	41.5 Ft.

COMPUTATION OF INITIAL VELOCITY

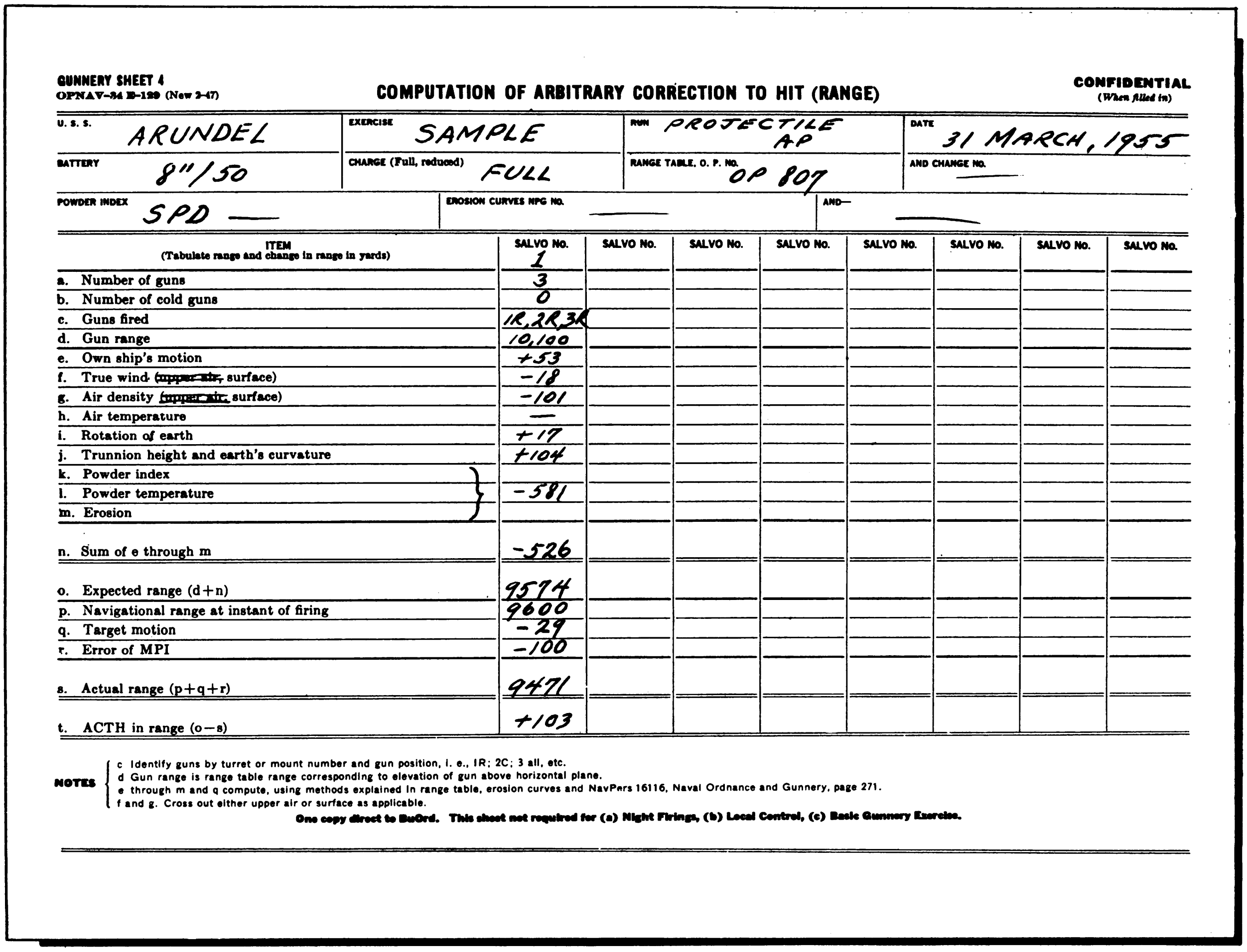
1	Powder Temp.Corr.(S)x(90-T)	11
2	Erosion Loss and Index Cor.	77
3	Total Velocity Loss (1)+(2)	88
4	Item R	2500
5	Expected I.V. (4)-(3)	2412
6	Item A	2500
7	I.V. Difference (5)-(6)	-88

	COMPUTATION IN RANGE	YARDS
8	I.V. Difference (7)x(D)÷10	-581
9	Own Ship Motion (LL)x(NN)x(H)÷10	+53
10	Wind (GG)x(II)x(G)÷10	-18
11	Air Density (100-Q)x(E)÷10	-101
12	Air Temperature (59-P)x(F)÷10	—
13	Trunnion and Curvature 100(Y)÷J	+104
14	Target Motion (BB)x(DD)x(I)÷10	-29
15	Rotation of Earth	+17

	COMPUTATION IN DEFLECTION	YARDS
16	Rotation of Earth	+5
17	Own Ship Motion (LL)x(OO)x(M)÷10	+108
18	Wind (GG)x(JJ)x(L)÷10	+11
19	Target Motion (100)x(BB)x(EE)x(N) ÷ (P)+(14)	(mils) +17

FIGURE B3.—Work sheet for preparing Gunnery Sheet 4 (8-inch).

BALLISTIC PROBLEMS 8"/55 GUN (Continued)



GUNNERY SHEET 4
OPNAV-34 B-129 (New 2-47)

COMPUTATION OF ARBITRARY CORRECTION TO HIT (RANGE)

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(When filled in)

U. S. S. ARUNDEL	EXERCISE SAMPLE	RUN PROJECTILE AP	DATE 31 MARCH, 1955
BATTERY 8"/50	CHARGE (Full, reduced) FULL	RANGE TABLE, O. P. NO. OP 807	AND CHANGE NO. —
POWDER INDEX SPD —	EROSION CURVES NPG NO. —	AND— —	

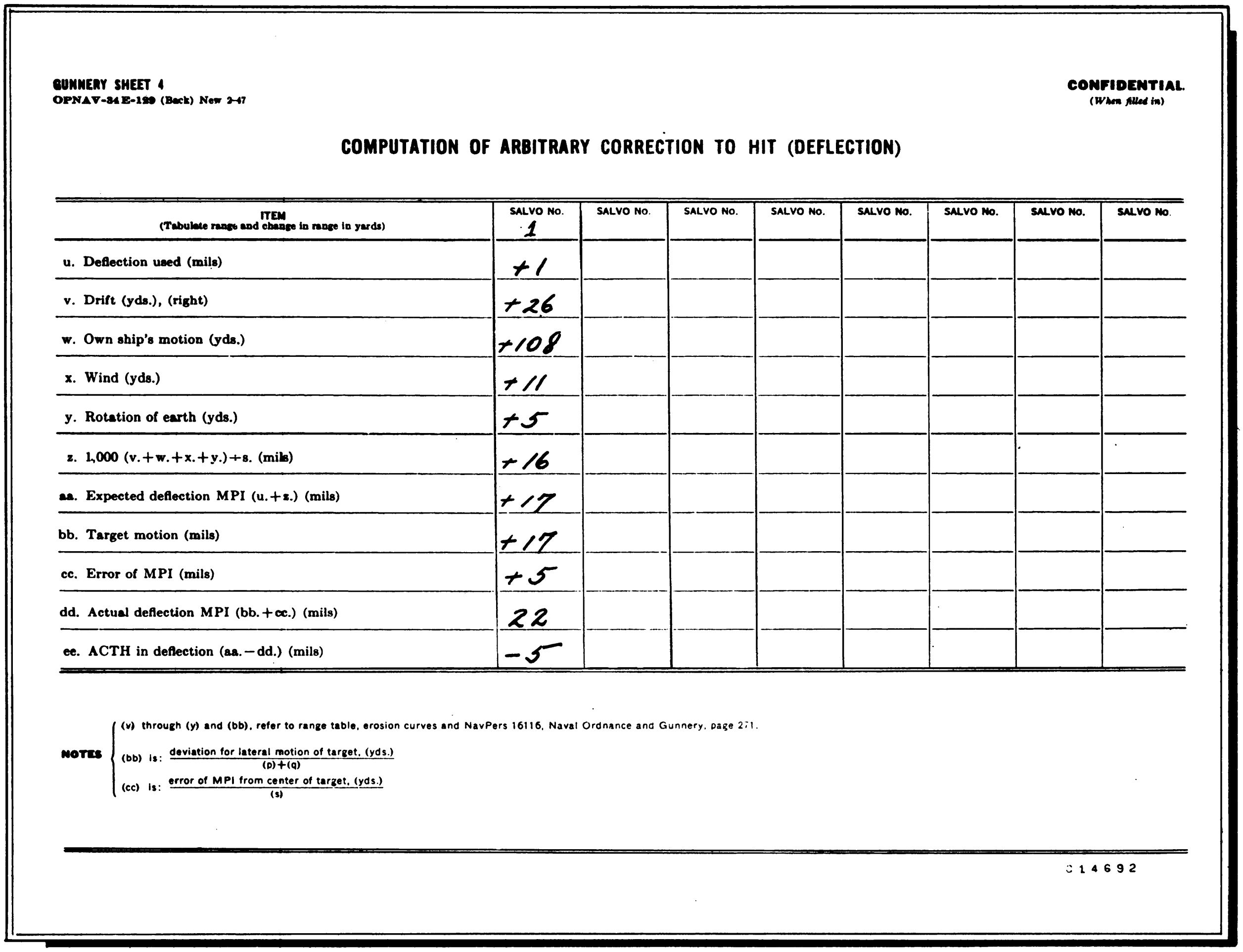
ITEM (Tabulate range and change in range in yards)	SALVO No. 1	SALVO No.	SALVO No.	SALVO No.	SALVO No.	SALVO No.	SALVO No.	SALVO No.
a. Number of guns	3							
b. Number of cold guns	0							
c. Guns fired	1R, 2R, 3R							
d. Gun range	10,100							
e. Own ship's motion	+53							
f. True wind (~~upper air,~~ surface)	−18							
g. Air density (~~upper air,~~ surface)	−101							
h. Air temperature	—							
i. Rotation of earth	+17							
j. Trunnion height and earth's curvature	+104							
k. Powder index								
l. Powder temperature	−581							
m. Erosion								
n. Sum of e through m	−526							
o. Expected range (d+n)	9574							
p. Navigational range at instant of firing	9600							
q. Target motion	−29							
r. Error of MPI	−100							
s. Actual range (p+q+r)	9471							
t. ACTH in range (o−s)	+103							

NOTES
- c Identify guns by turret or mount number and gun position, i. e., 1R; 2C; 3 all, etc.
- d Gun range is range table range corresponding to elevation of gun above horizontal plane.
- e through m and q compute, using methods explained in range table, erosion curves and NavPers 16116, Naval Ordnance and Gunnery, page 271.
- f and g. Cross out either upper air or surface as applicable.

One copy direct to BuOrd. This sheet not required for (a) Night Firings, (b) Local Control, (c) Basic Gunnery Exercise.

FIGURE B4.—Gunnery Sheet 4 (front)

BALLISTIC PROBLEMS 8″/55 GUN (Continued)



GUNNERY SHEET 4
OPNAV-34 E-129 (Back) New 2-47

CONFIDENTIAL
(When filled in)

COMPUTATION OF ARBITRARY CORRECTION TO HIT (DEFLECTION)

ITEM (Tabulate range and change in range in yards)	SALVO No. 1	SALVO No.	SALVO No.	SALVO No.	SALVO No.	SALVO No.	SALVO No.	SALVO No.
u. Deflection used (mils)	+1							
v. Drift (yds.), (right)	+26							
w. Own ship's motion (yds.)	+108							
x. Wind (yds.)	+11							
y. Rotation of earth (yds.)	+5							
z. 1,000 (v.+w.+x.+y.)÷s. (mils)	+16							
aa. Expected deflection MPI (u.+z.) (mils)	+17							
bb. Target motion (mils)	+17							
cc. Error of MPI (mils)	+5							
dd. Actual deflection MPI (bb.+cc.) (mils)	22							
ee. ACTH in deflection (aa.−dd.) (mils)	−5							

NOTES
(v) through (y) and (bb), refer to range table, erosion curves and NavPers 16116, Naval Ordnance and Gunnery, page 271.
(bb) is: $\frac{\text{deviation for lateral motion of target, (yds.)}}{(p)+(q)}$
(cc) is: $\frac{\text{error of MPI from center of target, (yds.)}}{(s)}$

C 14692

Figure B5.—Gunnery Sheet 4 (rear).

Appendix C

EXTRACTS FROM 5"/38 RANGE TABLE (AND ASSOCIATED MATERIAL)

Part 1. Air-Density Nomogram

Align (B) and (T) to get point on support (D).
Align (D) with (R) to get error in yards due to change in density of air.

EXAMPLE:

Given:	
Barometer	29.1 inches.
Temperature	80° F.
Range	8,000 yards.
Result:	
Error	+210 yards.

NOTE.—The best estimate of ballistic density to different altitudes is in very close, but not in exact agreement with standard density when surface conditions are standard. When surface density is not standard the disagreement is usually greater and is a function of surface density and maximum ordinate. Use of this nomogram will not give agreement with results obtained from Column 12 and surface observations only, but should be a more accurate figure, in that it takes into account the ratio between mean measured and standard density for the actual maximum ordinate obtained.

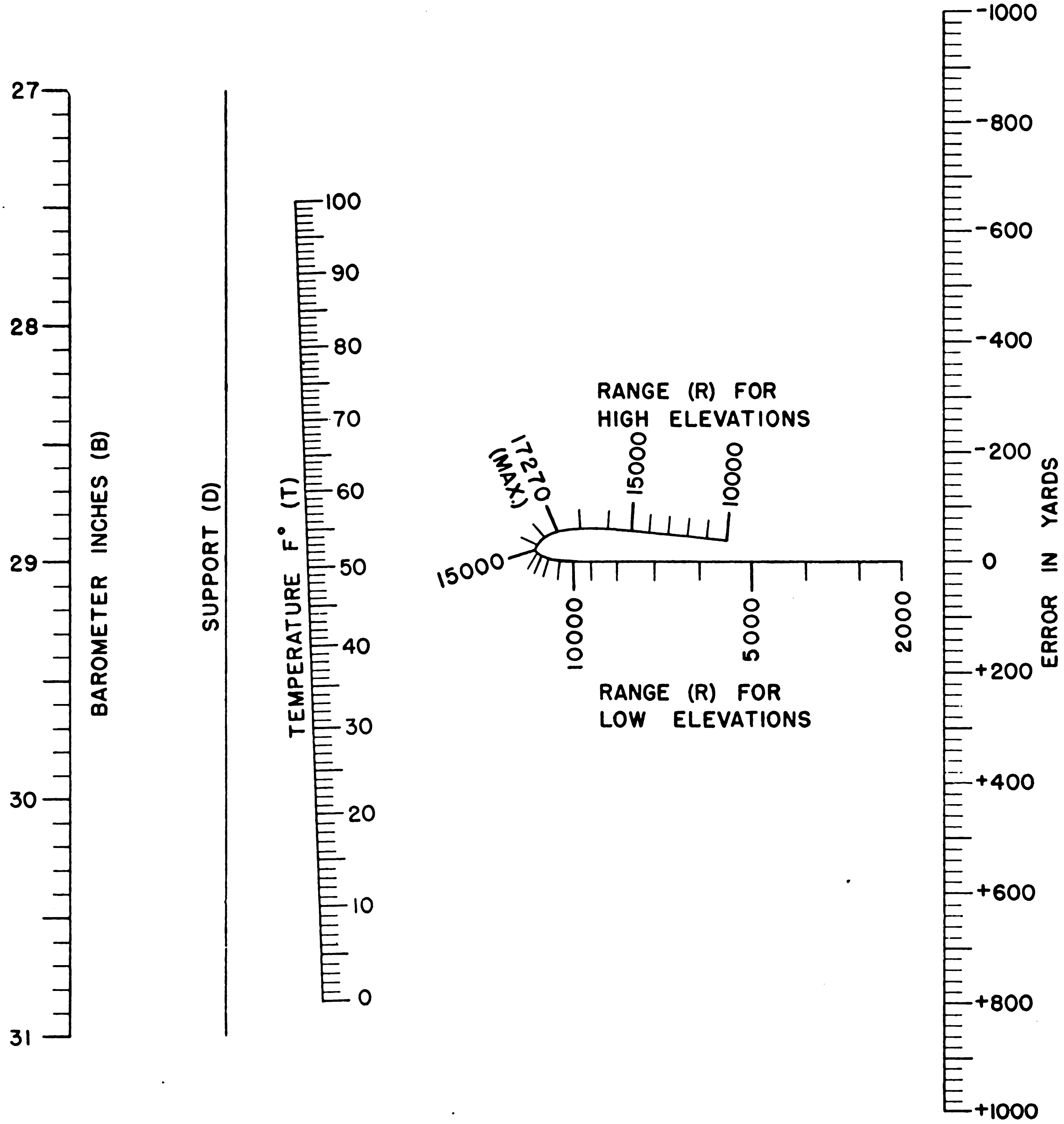


Figure C1.—Change in range for variation in density of air.

Appendix C, Part 2

EXTRACTS FROM RANGE TABLE FOR 5"/38 GUN

INITIAL VELOCITY=2,500 f. s.	WEIGHT OF PROJECTILE=55.18 POUNDS.
LENGTH OF PROJECTILE=4.1 CALIBERS.	RADIUS OF OGIVE=5.25 CALIBERS.

Range	Angle of elevation			Increase in angle of elevation for 100 yards, increase in range	Angle of fall		Time of flight	Striking velocity	Drift	Danger space for a target 20 feet high	Maximum ordinate
1	2		2a	2b	3		4	5	6	7	8
Yards	°	′	*Minutes*	*Minutes*	°	′	*Seconds*	*F. S.*	*Yards*	*Yards*	*Feet*
1,000		33.8	33.8	3.0		30	1.26	2,264	0.2	1,000	6
1,100		36.8	36.8	3.1		34	1.40	2,240	.3	1,100	8
1,200		39.9	39.9	3.1		38	1.53	2,217	.3	1,200	9
1,300		43.0	43.0	3.2		41	1.66	2,194	.4	1,300	11
1,400		46.2	46.2	3.2		45	1.80	2,171	.4	1,400	13
1,500		49.4	49.4	3.3		49	1.94	2,148	.4	1,500	15
1,600		52.7	52.7	3.3		53	2.08	2,125	.5	1,600	17
1,700		56.0	56.0	3.4		57	2.22	2,102	.5	1,700	20
1,800		59.4	59.4	3.4	1	01	2.37	2,079	.6	583	22
1,900	1	02.8	62.8	3.5	1	05	2.51	2,057	.7	487	25
2,000	1	06.3	66.3	3.5	1	10	2.66	2,034	.8	431	28
2,100	1	09.8	69.8	3.6	1	14	2.81	2,011	.9	388	31
2,200	1	13.4	73.4	3.6	1	19	2.96	1,989	1.0	354	35
2,300	1	17.0	77.0	3.7	1	24	3.11	1,967	1.1	325	38
2,400	1	20.7	80.7	3.7	1	29	3.26	1,944	1.3	300	42
2,500	1	24.4	84.4	3.8	1	34	3.42	1,922	1.5	279	46
2,600	1	28.2	88.2	3.9	1	40	3.58	1,900	1.7	261	51
2,700	1	32.1	92.1	3.9	1	45	3.73	1,879	1.9	245	55
2,800	1	36.0	96.0	4.0	1	51	3.90	1,857	2.2	230	60
2,900	1	40.0	100.0	4.0	1	56	4.06	1,835	2.5	217	65
3,000	1	44.0	104.0	4.1	2	02	4.22	1,814	3	205	71
3,100	1	48.1	108.1	4.2	2	08	4.39	1,793	3	193	77
3,200	1	52.3	112.3	4.2	2	15	4.56	1,772	3	182	83
3,300	1	56.5	116.5	4.3	2	21	4.73	1,751	3	172	89
3,400	2	00.8	120.8	4.4	2	28	4.90	1,730	3	164	96
3,500	2	05.2	125.2	4.5	2	35	5.07	1,710	4	157	103
3,600	2	09.7	129.7	4.5	2	42	5.25	1,689	4	150	110
3,700	2	14.2	134.2	4.6	2	49	5.43	1,669	4	143	118
3,800	2	18.8	138.8	4.7	2	56	5.61	1,648	5	136	126
3,900	2	23.5	143.5	4.7	3	04	5.80	1,628	5	130	134
4,000	2	28.2	148.2	4.8	3	12	5.98	1,609	6	124	143

EXTRACTS FROM RANGE TABLE FOR 5″/38 GUN (Continued)

INITIAL VELOCITY = 2,500 f. s. WEIGHT OF PROJECTILE = 55.18 POUNDS.

LENGTH OF PROJECTILE = 4.1 CALIBERS. RADIUS OF OGIVE = 5.25 CALIBERS.

Change of range for variation of +10 feet per second initial velocity	Change of range for variation of −1 pounds in weight of projectile	Change of range for variation in density of air of −10 per cent	Change of range for variation of temperature of air of −10° F.	Change of range for wind component in plane of fire of 10 knots	Change of range for motion of gun in plane of fire of 10 knots	Change of range for motion of target in plane of fire of 10 knots	Deviation for lateral wind component of 10 knots	Deviation for lateral motion of gun perpendicular to line of fire, speed of 10 knots	Deviation for lateral motion of target perpendicular to line of fire, speed of 10 knots	Change in height of impact for variation of 100 yards in sight bar
10	11	12	12a	13	14	15	16	17	18	19
Yards	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Feet*
7	8	8	1	1	6	7	0.3	6.8	7.1	3
8	9	9	1	1	7	8	.4	7.5	7.9	3
9	10	10	1	1	8	9	.5	8.1	8.6	3
10	10	11	1	1	8	9	.6	8.7	9.3	4
10	11	13	1	1	9	10	.7	9.4	10.1	4
11	12	15	2	2	9	11	.8	10.1	10.9	4
12	12	17	2	2	10	12	.9	10.8	11.7	5
12	13	19	2	2	10	12	1.0	11.5	12.5	5
13	13	21	2	2	11	13	1.1	12.2	13.3	5
14	14	23	2	2	12	14	1.3	12.8	14.1	6
15	14	26	2	2	13	15	1.5	13.5	15.0	6
15	15	28	2	3	13	16	1.6	14.2	15.8	6
16	15	31	3	3	14	17	1.8	14.9	16.7	7
16	15	34	3	3	15	18	2.0	15.5	17.5	7
17	16	37	3	3	15	18	2.2	16.2	18.4	8
18	16	40	3	3	16	19	2.5	16.8	19.3	8
18	16	44	3	4	16	20	2.7	17.4	20.1	9
19	16	47	4	4	17	21	2.9	18.1	21.0	9
20	17	50	4	4	18	22	3.2	18.7	21.9	10
20	17	53	4	4	19	23	3.4	19.4	22.8	10
21	17	57	4	5	19	24	4	20	24	11
22	17	62	4	5	20	25	4	21	25	11
22	17	66	5	5	21	26	4	22	26	12
23	17	70	5	6	21	27	5	22	27	12
24	17	74	5	6	22	28	5	23	28	13
24	17	78	6	6	23	29	5	24	29	14
25	17	83	6	7	23	30	5	25	30	14
25	17	88	6	7	24	31	6	25	31	15
26	17	92	6	8	24	32	6	26	32	15
26	17	97	7	8	25	33	6	27	33	16
27	16	102	7	8	26	34	7	27	34	17

EXTRACTS FROM RANGE TABLE FOR 5"/38 GUN (Continued)

INITIAL VELOCITY=2,500 f. s. WEIGHT OF PROJECTILE=55.18 POUNDS.

LENGTH OF PROJECTILE=4.1 CALIBERS. RADIUS OF OGIVE=5.25 CALIBERS.

Range	Angle of elevation			Increase in angle of elevation for 100 yards, increase in range	Angle of fall		Time of flight	Striking velocity	Drift	Danger space for a target 20 feet high	Maximum ordinate
1	2		2a	2b	3		4	5	6	7	8
Yards	°	′	*Minutes*	*Minutes*	°	′	*Seconds*	*F. S.*	*Yards*	*Yards*	*Feet*
7,000	5	40	340	8	9	33	12.81	1,119	22	40	666
7,100	5	48	348	8	9	51	13.08	1,109	23	38	695
7,200	5	56	356	9	10	10	13.36	1,099	24	37	726
7,300	6	05	365	9	10	28	13.64	1,090	25	36	758
7,400	6	14	374	10	10	47	13.92	1,081	26	35	790
7,500	6	24	384	9	11	07	14.20	1,073	27	34	823
7,600	6	33	393	9	11	27	14.49	1,065	28	33	857
7,700	6	42	402	10	11	47	14.78	1,057	30	32	893
7,800	6	52	412	10	12	08	15.07	1,050	31	31	930
7,900	7	02	422	10	12	29	15.36	1,044	32	30	967
8,000	7	12	432	10	12	50	15.65	1,038	33	29	1,005
8,100	7	22	442	10	13	12	15.95	1,033	35	28	1,045
8,200	7	32	452	10	13	34	16.26	1,029	36	28	1,085
8,300	7	42	462	10	13	56	16.56	1,024	37	27	1,130
8,400	7	52	472	11	14	17	16.86	1,019	39	26	1,175
8,500	8	03	483	11	14	39	17.16	1,014	40	25	1,220
8,600	8	14	494	10	15	01	17.47	1,009	42	25	1,265
8,700	8	24	504	11	15	24	17.79	1,004	43	24	1,315
8,800	8	35	515	11	15	46	18.10	999	45	24	1,365
8,900	8	46	526	11	16	09	18.41	994	47	23	1,415
9,000	8	57	537	11	16	32	18.72	990	49	22	1,465
9,100	9	08	548	11	16	55	19.04	986	51	22	1,520
9,200	9	19	559	11	17	18	19.37	982	53	21	1,575
9,300	9	30	570	12	17	41	19.69	978	55	21	1,630
9,400	9	42	582	12	18	05	20.01	975	57	20	1,685
9,500	9	54	594	12	18	29	20.33	972	59	20	1,745
9,600	10	06	606	12	18	53	20.66	969	61	19	1,805
9,700	10	18	618	12	19	17	21.00	965	63	19	1,865
9,800	10	30	630	12	19	41	21.34	962	65	19	1,930
9,900	10	42	642	13	20	06	21.67	958	67	18	1,995
10,000	10	55	655	14	20	31	22.00	955	69	18	2,060

EXTRACTS FROM RANGE TABLE FOR 5″/38 GUN (Continued)

INITIAL VELOCITY=2,500 f. s. WEIGHT OF PROJECTILE=55.18 POUNDS.

LENGTH OF PROJECTILE=4.1 CALIBERS. RADIUS OF OGIVE=5.25 CALIBERS.

Change of range for variation of +10 feet per second initial velocity	Change of range for variation of −1 pounds in weight of projectile	Change of range for variation in density of air of −10 per cent	Change of range for variation of temperature of air of −10° F.	Change of range for wind component in plane of fire of 10 knots	Change of range for motion of gun in plane of fire of 10 knots	Change of range for motion of target in plane of fire of 10 knots	Deviation for lateral wind component of 10 knots	Deviation for lateral motion of gun perpendicular to line of fire, speed of 10 knots	Deviation for lateral motion of target perpendicular to line of fire, speed of 10 knots	Change in height of impact for variation of 100 yards in sight bar
10	11	12	12a	13	14	15	16	17	18	19
Yards	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Feet*
40	−3	300	17	32	40	72	24	48	72	50
40	−4	308	18	34	40	74	25	49	74	52
40	−5	315	18	35	40	75	25	50	75	54
41	−6	323	18	36	41	77	26	51	77	55
41	−6	330	18	37	41	78	27	51	78	57
42	−7	337	18	38	42	80	28	52	80	59
42	−8	344	19	40	42	82	29	53	82	61
42	−9	352	19	41	42	83	30	53	83	63
42	−10	360	19	42	43	85	31	54	85	65
42	−11	367	19	43	43	86	31	55	86	66
43	−12	374	19	45	43	88	32	56	88	68
43	−13	381	19	47	44	91	33	57	91	70
43	−14	389	19	49	44	93	34	58	93	72
43	−15	396	19	50	44	94	35	59	94	74
44	−16	402	19	51	44	95	36	59	95	76
44	−17	408	19	52	44	96	37	59	96	78
44	−18	415	19	54	44	98	38	60	98	80
44	−18	421	18	56	44	100	39	61	100	83
45	−19	427	18	57	45	102	40	62	102	85
45	−20	434	18	59	45	104	41	63	104	87
45	−21	440	18	60	45	105	42	63	105	89
46	−22	446	17	62	45	107	43	64	107	91
46	−22	452	17	64	45	109	44	65	109	93
46	−23	458	17	66	45	111	45	66	111	96
46	−24	464	16	68	45	113	47	66	113	98
46	−25	470	16	69	45	114	48	67	114	100
47	−25	475	16	71	45	116	49	67	116	103
47	−26	481	15	73	45	118	50	68	118	105
47	−27	488	15	75	45	120	51	69	120	107
47	−28	495	15	76	46	122	52	70	122	110
48	−29	501	14	78	46	124	53	71	124	112

EXTRACTS FROM RANGE TABLE FOR 5"/38 GUN (Continued)

INITIAL VELOCITY=2,500 f. s.	WEIGHT OF PROJECTILE=55.18 POUNDS.
LENGTH OF PROJECTILE=4.1 CALIBERS.	RADIUS OF OGIVE=5.25 CALIBERS.

Range	Angle of elevation			Increase in angle of elevation for 100 yards, increase in range	Angle of fall		Time of flight	Striking velocity	Drift	Danger space for a target 20 feet high	Maximum ordinate
1	2		2a	2b	3		4	5	6	7	8
Yards	°	′	*Minutes*	*Minutes*	°	′	*Seconds*	*F. S.*	*Yards*	*Yards*	*Feet*
10, 000	10	55	655	14	20	31	22. 00	955	69	18	2, 060
10, 100	11	09	669	13	20	55	22. 34	952	71	17	2, 125
10, 200	11	22	682	13	21	20	22. 69	949	73	17	2, 195
10, 300	11	35	695	13	21	45	23. 04	946	75	17	2, 265
10, 400	11	48	708	12	22	10	23. 39	943	77	16	2, 340
10, 500	12	00	720	13	22	36	23. 73	940	80	16	2, 415
10, 600	12	13	733	14	23	01	24. 08	937	82	16	2, 490
10, 700	12	27	747	14	23	27	24. 43	935	85	15	2, 565
10, 800	12	41	761	15	23	53	24. 79	932	87	15	2, 645
10, 900	12	56	776	14	24	19	25. 15	930	90	15	2, 725
11, 000	13	10	790	14	24	46	25. 51	927	93	14	2, 810
11, 100	13	24	804	15	25	12	25. 88	925	95	14	2, 895
11, 200	13	39	819	15	25	38	26. 25	923	98	14	2, 980
11, 300	13	54	834	15	26	05	26. 62	921	101	14	3, 065
11, 400	14	09	849	16	26	32	26. 99	918	104	13	3, 155
11, 500	14	25	865	16	26	59	27. 36	916	107	13	3, 245
11, 600	14	41	881	16	27	26	27. 74	914	110	13	3, 340
11, 700	14	57	897	16	27	53	28. 12	913	113	13	3, 435
11, 800	15	13	913	16	28	20	28. 50	911	116	12	3, 530
11, 900	15	29	929	16	28	48	28. 89	909	119	12	3, 630
12, 000	15	45	945	16	29	16	29. 28	908	123	12	3, 730
12, 100	16	01	961	17	29	44	29. 67	907	126	12	3, 835
12, 200	16	18	978	17	30	12	30. 07	906	129	11	3, 940
12, 300	16	35	995	17	30	40	30. 47	904	133	11	4, 050
12, 400	16	52	1, 012	18	31	08	30. 87	903	136	11	4, 160
12, 500	17	10	1, 030	18	31	37	31. 28	902	140	11	4, 270
12, 600	17	28	1, 048	19	32	05	31. 69	901	144	11	4, 385
12, 700	17	47	1, 067	18	32	34	32. 11	900	148	10	4, 505
12, 800	18	05	1, 085	18	33	02	32. 53	900	152	10	4, 625
12, 900	18	23	1, 103	18	33	31	32. 96	899	156	10	4, 745
13, 000	18	41	1, 121	19	34	00	33. 38	898	160	10	4, 870

EXTRACTS FROM RANGE TABLE FOR 5″/38 GUN (Continued)

INITIAL VELOCITY=2,500 f. s.

WEIGHT OF PROJECTILE=55.18 POUNDS.

LENGTH OF PROJECTILE=4.1 CALIBERS.

RADIUS OF OGIVE=5.25 CALIBERS.

Change of range for variation of +10 feet per second initial velocity 10	Change of range for variation of −1 pounds in weight of projectile 11	Change of range for variation in density of air of −10 per cent 12	Change of range for variation of temperature of air of −10° F. 12a	Change of range for wind component in plane of fire of 10 knots 13	Change of range for motion of gun in plane of fire of 10 knots 14	Change of range for motion of target in plane of fire of 10 knots 15	Deviation for lateral wind component of 10 knots 16	Deviation for lateral motion of gun perpendicular to line of fire, speed of 10 knots 17	Deviation for lateral motion of target perpendicular to line of fire, speed of 10 knots 18	Change in height of impact for variation of 100 yards in sight bar 19
Yards	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Feet*
48	—29	501	14	78	46	124	53	71	124	112
48	−30	506	14	80	46	126	55	71	126	115
48	−30	512	14	82	46	128	56	72	128	117
48	−31	518	13	84	46	130	57	73	130	120
48	−32	524	13	86	46	132	58	74	132	122
49	−33	531	13	87	47	134	59	75	134	125
49	−34	537	12	89	47	136	61	75	136	127
49	−35	543	12	91	47	138	62	76	138	130
49	−35	549	12	93	47	140	63	77	140	133
50	−36	555	11	95	47	142	65	77	142	136
50	−37	561	11	97	47	144	66	78	144	138
50	−38	567	10	99	47	146	67	79	146	141
50	−39	573	10	101	47	148	69	79	148	144
50	−39	579	10	104	46	150	70	80	150	147
51	−40	585	9	106	46	152	72	80	152	150
51	−41	591	9	108	46	154	73	81	154	153
51	−42	597	8	110	46	156	74	82	156	156
51	−43	604	8	112	46	158	76	82	158	159
51	−44	610	8	114	46	160	77	83	160	162
52	−45	616	7	116	46	162	78	84	162	165
52	−46	623	7	119	46	165	80	85	165	168
52	−46	629	6	121	46	167	81	86	167	171
52	−47	636	6	124	46	170	83	87	170	175
52	−48	642	6	126	46	172	85	87	172	178
53	−49	649	5	128	46	174	86	88	174	181
53	−50	656	5	130	46	176	87	89	176	185
53	−51	663	4	132	46	178	89	89	178	188
53	−52	669	4	134	46	180	90	90	180	191
53	−53	676	3	137	46	183	92	91	183	195
54	−54	683	3	139	47	186	94	92	186	199
54	−55	690	3	141	47	188	95	93	188	202

EXTRACTS FROM RANGE TABLE FOR 5"/38 GUN (Continued)

INITIAL VELOCITY=2,500 f. s. WEIGHT OF PROJECTILE=55.18 POUNDS.

LENGTH OF PROJECTILE=4.1 CALIBERS. RADIUS OF OGIVE=5.25 CALIBERS.

Range	Angle of elevation			Increase in angle of elevation for 100 yards, increase in range	Angle of fall		Time of flight	Striking velocity	Drift	Danger space for a target 20 feet high	Maximum ordinate
1	2		2a	2b	3		4	5	6	7	8
Yards	°	'	*Minutes*	*Minutes*	°	'	*Seconds*	*F. S.*	*Yards*	*Yards*	*Feet*
13,000	18	41	1,121	19	34	00	33.38	898	160	10	4,870
13,100	19	00	1,140	19	34	29	33.80	898	164	10	5,000
13,200	19	19	1,159	19	34	58	34.23	898	169	10	5,130
13,300	19	38	1,178	19	35	28	34.67	897	173	9	5,260
13,400	19	57	1,197	20	35	57	35.12	897	178	9	5,395
13,500	20	17	1,217	20	36	26	35.58	897	183	9	5,535
13,600	20	37	1,237	21	36	56	36.03	897	188	9	5,680
13,700	20	58	1,258	21	37	26	36.48	897	193	9	5,825
13,800	21	19	1,279	21	37	56	36.94	897	198	9	5,975
13,900	21	40	1,300	21	38	26	37.41	898	203	8	6,125
14,000	22	01	1,321	21	38	56	37.89	898	208	8	6,280
14,100	22	22	1,342	22	39	27	38.37	898	213	8	6,440
14,200	22	44	1,364	22	39	57	38.85	899	219	8	6,605
14,300	23	06	1,386	23	40	28	39.33	900	224	8	6,770
14,400	23	29	1,409	24	40	59	39.83	900	230	8	6,940
14,500	23	53	1,433	24	41	30	40.34	901	236	8	7,115
14,600	24	17	1,457	24	42	01	40.85	902	242	7	7,295
14,700	24	41	1,481	24	42	32	41.37	904	248	7	7,480
14,800	25	05	1,505	25	43	04	41.89	905	254	7	7,670
14,900	25	30	1,530	26	43	36	42.43	906	261	7	7,865
15,000	25	56	1,556	26	44	08	42.98	908	268	7	8,065
15,100	26	22	1,582	26	44	40	43.53	909	275	7	8,270
15,200	26	48	1,608	27	45	12	44.09	911	282	7	8,480
15,300	27	15	1,635	28	45	45	44.66	913	289	6	8,700
15,400	27	43	1,663	29	46	18	45.25	915	297	6	8,925
15,500	28	12	1,692	29	46	52	45.86	917	305	6	9,155
15,600	28	41	1,721	30	47	25	46.48	919	313	6	9,395
15,700	29	11	1,751	31	47	59	47.11	921	321	6	9,645
15,800	29	42	1,782	32	48	34	47.75	924	330	6	9,905
15,900	30	14	1,814	33	49	09	48.40	926	339	6	10,175
16,000	30	47	1,847	34	49	45	49.07	929	349	6	10,450

EXTRACTS FROM RANGE TABLE FOR 5"/38 GUN (Continued)

INITIAL VELOCITY=2,500 f. s.

WEIGHT OF PROJECTILE=55.18 POUNDS.

LENGTH OF PROJECTILE=4.1 CALIBERS.

RADIUS OF OGIVE=5.25 CALIBERS.

Change of range for variation of +10 feet per second initial velocity	Change of range for variation of −1 pounds in weight of projectile	Change of range for variation in density of air of −10 per cent	Change of range for variation of temperature of air of −10° F.	Change of range for wind component in plane of fire of 10 knots	Change of range for motion of gun in plane of fire of 10 knots	Change of range for motion of target in plane of fire of 10 knots	Deviation for lateral wind component of 10 knots	Deviation for lateral motion of gun perpendicular to line of fire, speed of 10 knots	Deviation for lateral motion of target perpendicular to line of fire, speed of 10 knots	Change in height of impact for variation of 100 yards in sight bar
10	11	12	12a	13	14	15	16	17	18	19
Yards	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Feet*
54	−55	690	3	141	47	188	95	93	188	202
54	−56	698	2	144	46	190	97	93	190	206
54	−57	705	2	147	46	193	99	94	193	210
55	−58	712	2	149	46	195	100	95	195	214
55	−59	719	1	151	47	198	102	96	198	218
55	−60	726	1	153	47	200	103	97	200	222
55	−61	734	0	156	47	203	105	98	203	226
56	−62	741	0	158	47	205	106	99	205	230
56	−63	749	0	161	47	208	108	100	208	234
56	−64	756	−1	163	48	211	110	101	211	238
56	−65	763	−2	165	48	213	111	102	213	242
57	−66	771	−2	168	48	216	113	103	216	247
57	−67	779	−2	171	48	219	115	104	219	251
57	−68	787	−2	173	48	221	116	105	221	256
57	−69	795	−3	176	48	224	118	106	224	261
57	−70	802	−3	178	49	227	120	107	227	265
58	−71	810	−4	181	49	230	122	108	230	270
58	−72	818	−4	183	50	233	124	109	233	275
59	−74	827	−4	186	50	236	126	110	236	280
59	−75	835	−5	189	50	239	128	111	239	286
59	−76	843	−5	192	50	242	129	113	242	291
60	−77	852	−6	194	51	245	131	114	245	297
60	−78	860	−6	197	51	248	133	115	248	302
60	−79	869	−6	200	51	251	135	116	251	308
60	−80	878	−7	203	52	255	137	118	255	314
61	−82	887	−7	206	52	258	139	119	258	320
61	−83	896	−7	208	53	261	141	120	261	326
62	−84	905	−8	211	54	265	143	122	265	333
62	−85	915	−8	214	54	268	145	123	268	340
62	−87	925	−8	218	54	272	148	124	272	347
63	−88	935	−8	221	55	276	150	126	276	354

EXTRACTS FROM RANGE TABLE FOR 5"/38 GUN (Continued)

INITIAL VELOCITY = 2,500 f. s. WEIGHT OF PROJECTILE = 55.18 POUNDS.

LENGTH OF PROJECTILE = 4.1 CALIBERS. RADIUS OF OGIVE = 5.25 CALIBERS.

Range	Angle of elevation		Increase in angle of elevation for 100 yards, increase in range		Angle of fall		Time of flight	Striking velocity	Drift	Danger space for a target 20 feet high	Maximum ordinate
1	2		2a	2b	3		4	5	6	7	8
Yards	°	′	*Minutes*	*Minutes*	°	′	*Seconds*	*F. S.*	*Yards*	*Yards*	*Feet*
16,000	30	47	1,847	34	49	45	49.07	929	349	6	10,450
16,100	31	21	1,881	35	50	21	49.77	932	359	6	10,740
16,200	31	56	1,916	36	50	58	50.50	935	369	5	11,050
16,300	32	32	1,952	37	51	35	51.25	938	380	5	11,370
16,400	33	09	1,989	40	52	13	52.02	941	392	5	11,710
16,500	33	49	2,029	43	52	53	52.82	945	405	5	12,070
16,600	34	32	2,072	47	53	35	53.66	949	418	5	12,450
16,700	35	19	2,119	50	54	19	54.56	953	432	5	12,860
16,800	36	09	2,169	54	55	04	55.53	958	447	5	13,310
16,900	37	03	2,223	62	55	52	56.60	963	464	5	13,810
17,000	38	05	2,285	74	56	45	57.80	969	484	4	14,370
17,100	39	19	2,359	92	57	46	59.20	976	508	4	15,020
17,200	40	51	2,451		59	01	60.94	985	538	4	15,870
17,270	44	35	2,675		61	53	65.7	1,006	625	4	18,000
17,200	48	09	2,889		64	28	68.8	1,022	687	3	20,080
17,100	49	32	2,972	−83	65	25	70.2	1,026	716	3	20,870
17,000	50	33	3,033	−61	66	09	71.3	1,029	737	3	21,430
16,900	51	23	3,083	−50	66	44	72.1	1,031	754	3	21,900
16,800	52	07	3,127	−44	67	14	72.8	1,033	769	3	22,310
16,700	52	46	3,166	−39	67	42	73.5	1,034	782	3	22,670
16,600	53	22	3,202	−36	68	08	74.1	1,035	795	3	23,000
16,500	53	57	3,237	−35	68	32	74.6	1,036	807	3	23,300
16,400	54	31	3,271	−34	68	54	75.1	1,036	818	3	23,610
16,300	55	04	3,304	−33	69	16	75.6	1,037	829	3	23,910
16,200	55	35	3,335	−31	69	37	76.1	1,038	840	2	24,200
16,100	56	05	3,365	−30	69	57	76.6	1,038	851	2	24,470
16,000	56	34	3,394	−29	70	17	77.1	1,039	861	2	24,720
15,900	57	02	3,422	−28	70	36	77.5	1,039	870	2	24,960
15,800	57	28	3,448	−26	70	54	77.9	1,038	880	2	25,200
15,700	57	53	3,473	−25	71	11	78.3	1,038	889	2	25,430
15,600	58	18	3,498	−25	71	29	78.7	1,037	898	2	25,640

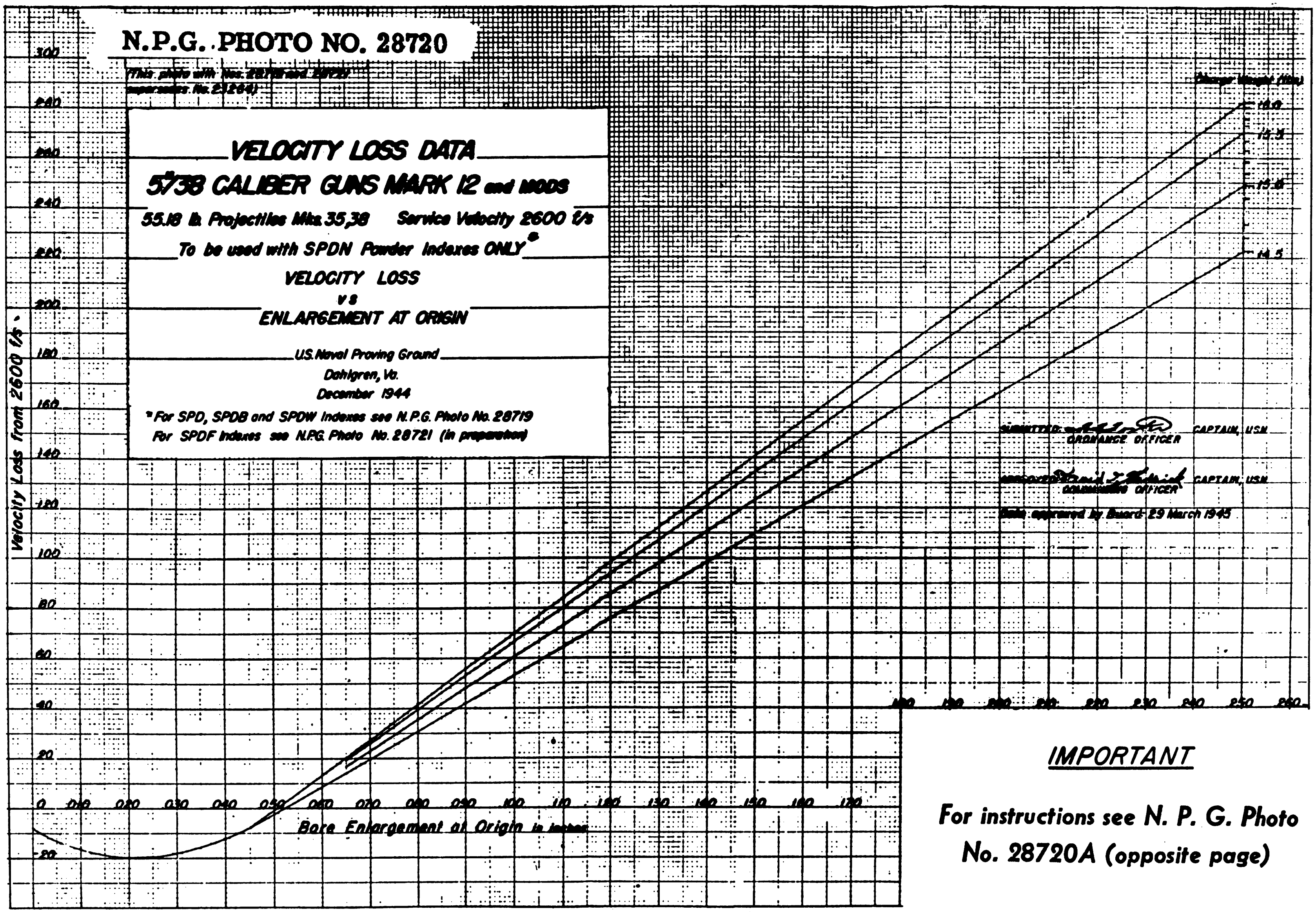
EXTRACTS FROM RANGE TABLE FOR 5″/38 GUN (Continued)

INITIAL VELOCITY=2,500 f. s.
WEIGHT OF PROJECTILE=55.18 POUNDS.
LENGTH OF PROJECTILE=4.1 CALIBERS.
RADIUS OF OGIVE=5.25 CALIBERS.

Change of range for variation of +10 feet per second initial velocity	Change of range for variation of −1 pounds in weight of projectile	Change of range for variation in density of air of −10 per cent	Change of range for variation of temperature of air of −10° F.	Change of range for wind component in plane of fire of 10 knots	Change of range for motion of gun in plane of fire of 10 knots	Change of range for motion of target in plane of fire of 10 knots	Deviation for lateral wind component of 10 knots	Deviation for lateral motion of gun perpendicular to line of fire, speed of 10 knots	Deviation for lateral motion of target perpendicular to line of fire, speed of 10 knots	Change in height of impact for variation of 100 yards in sight bar
10	11	12	12a	13	14	15	16	17	18	19
Yards	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Yards*	*Feet*
63	—88	935	—8	221	55	276	150	126	276	354
63	−89	946	−8	224	56	280	153	127	280	362
64	−91	957	−9	227	57	284	155	129	284	370
64	−93	969	−9	230	58	288	158	130	288	378
64	−94	981	−9	234	59	293	161	132	293	387
65	−96	993	−9	238	60	298	164	134	298	397
65	—98	1,006	−9	241	61	302	166	136	302	407
66	—99	1,019	−10	245	62	307	169	138	307	418
66	−101	1,033	−10	249	64	313	173	140	313	429
66	−103	1,048	−10	254	65	319	176	143	319	442
67	−106	1,065	−10	258	67	325	180	145	325	458
67	−109	1,083	−9	263	70	333	185	148	333	476
68	−112	1,104	−9	270	73	343	190	153	343	500
69	−116	1,143	−9	283	87	370	206	164	370	561
70	−118	1,150	−8	291	97	388	214	174	388	628
70	−117	1,145	−7	293	102	395	218	177	395	657
70	−116	1,140	−7	295	106	401	221	180	401	679
70	−115	1,136	−7	296	110	406	223	183	406	698
70	−115	1,133	−7	297	113	410	226	184	410	715
70	−114	1,130	−6	298	116	414	228	186	414	732
69	−114	1,126	−6	298	119	417	229	188	417	748
69	−114	1,123	−6	298	122	420	231	189	420	763
69	−113	1,119	−6	299	124	423	232	191	423	777
68	−113	1,115	−6	299	127	426	234	192	426	792
68	−113	1,112	−6	299	130	429	236	193	429	807
68	−113	1,109	−6	299	133	432	237	195	432	822
68	−113	1,106	−6	299	135	434	238	196	434	837
67	−112	1,102	−5	299	137	436	239	197	436	852
67	−112	1,098	−5	299	140	439	241	198	439	866
67	−112	1,094	−5	299	142	441	242	199	441	881
66	−111	1,090	−5	299	144	443	243	200	443	896

Appendix C, Part 3

VELOCITY-LOSS DATA CURVES



IMPORTANT

For instructions see N. P. G. Photo No. 28720A (opposite page)

VELOCITY-LOSS DATA CURVES (Continued)

N.P.G. Photo No. 28720 A

INSTRUCTIONS for use of N.P.G. Photo No. 28720 (opposite page):

I Powder Index	II Charge Correction	III Velocity Loss
0 to 4103 4105 to 4120 4122, 4123, 4331 4347, 4348	0.15 lbs	+21 f/s
5609 to 5616 5618	0	+6 f/s

A If powder index to be used is NOT listed in Column I:

1. *Enter curves with present estimated bore enlargement and charge weight as marked on powder tank (interpolating if necessary) and obtain velocity loss.*

B If powder index to be used IS listed in Column I:

1. *Add the charge correction given in Column II to the charge weight marked on powder tank and obtain corrected charge weight.*
2. *Enter the curves with this corrected charge weight (interpolating if necessary) and present estimated bore enlargement and obtain velocity loss due to erosion.*
3. *To this loss add the loss given in Column III to obtain velocity loss due to both erosion and charge weight as assembled.*

EXAMPLE:

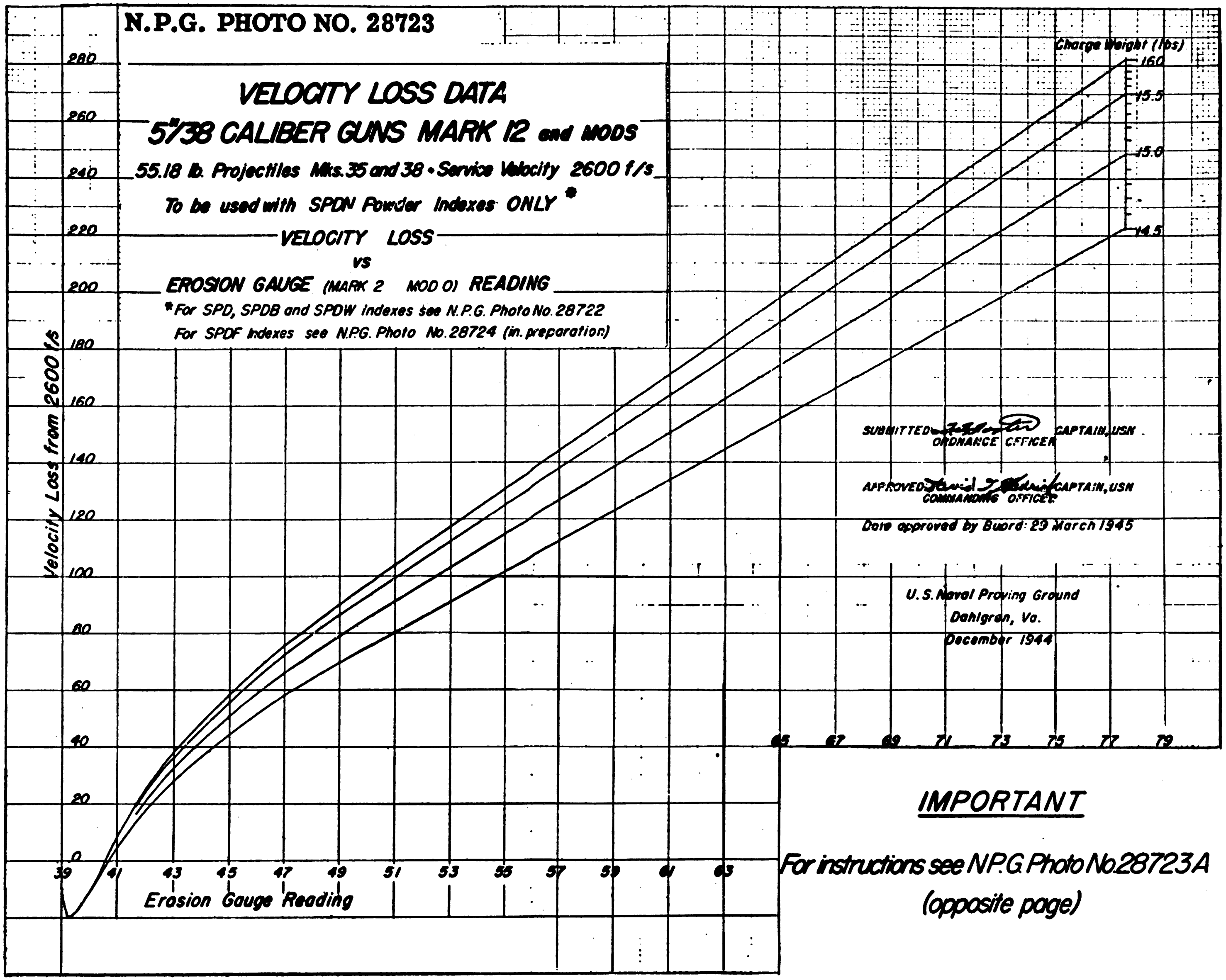
Given Index SPDN 4103 (charge weight marked on tank 14.78 lbs) and Bore Enlargement 0".190.

1. *Corrected charge weight is 14.78 + .15 = 14.93 lbs.*
2. *Velocity loss due to erosion is 171 f/s.*
3. *Total velocity loss is 171 + 21 = 192 f/s.*

U.S. Naval Proving Ground
Dahlgren, Va.
December 1944

Date approved by BuOrd:
29 March 1945

VELOCITY-LOSS DATA CURVES (Continued)



N.P.G. PHOTO NO. 28723

VELOCITY LOSS DATA

5"/38 CALIBER GUNS MARK 12 and MODS

55.18 lb. Projectiles Mks. 35 and 38 • Service Velocity 2600 f/s

To be used with SPDN Powder Indexes ONLY *

VELOCITY LOSS

vs

EROSION GAUGE (MARK 2 MOD 0) READING

*For SPD, SPDB and SPDW indexes see N.P.G. Photo No. 28722

For SPDF Indexes see N.P.G. Photo No. 28724 (in preparation)

SUBMITTED ——— CAPTAIN, USN
ORDNANCE OFFICER

APPROVED David I. ——— CAPTAIN, USN
COMMANDING OFFICER

Date approved by Buord: 29 March 1945

U.S. Naval Proving Ground
Dahlgren, Va.
December 1944

IMPORTANT

For instructions see N.P.G. Photo No. 28723A (opposite page)

VELOCITY-LOSS DATA CURVES (Continued)

N.P.G. Photo No. 28723A

INSTRUCTIONS for use of N.P.G. Photo No. 28723 (opposite page):

I *Powder Index*	*II* *Charge Correction*	*III* *Velocity Loss*
0 to 4103 *4105 to 4120* *4122, 4123, 4331* *4347, 4348*	*0.15 lbs.*	*+21 f/s*
5609 to 5616 *5618*	*0*	*+6 f/s*

A If powder index to be used is NOT listed in Column I:

1. Enter curves with erosion gauge reading and charge weight as marked on powder tank (interpolating if necessary) and obtain velocity loss.

B If powder index to be used IS listed in Column I:

1. Add the charge correction given in Column II to the charge weight marked on powder tank and obtain corrected charge weight.

2. Enter the curves with this corrected charge weight (interpolating if necessary) and erosion gauge reading and obtain velocity loss due to erosion.

3. To this loss add the loss given in Column III to obtain velocity loss due to both erosion and charge weight as assembled.

EXAMPLE:

Given Index SPDN 4103 (charge weight marked on tank 14.78 lbs) and Erosion Gauge Reading 65.1

1. Corrected charge weight is 14.78 + .15 = 14.93 lbs.

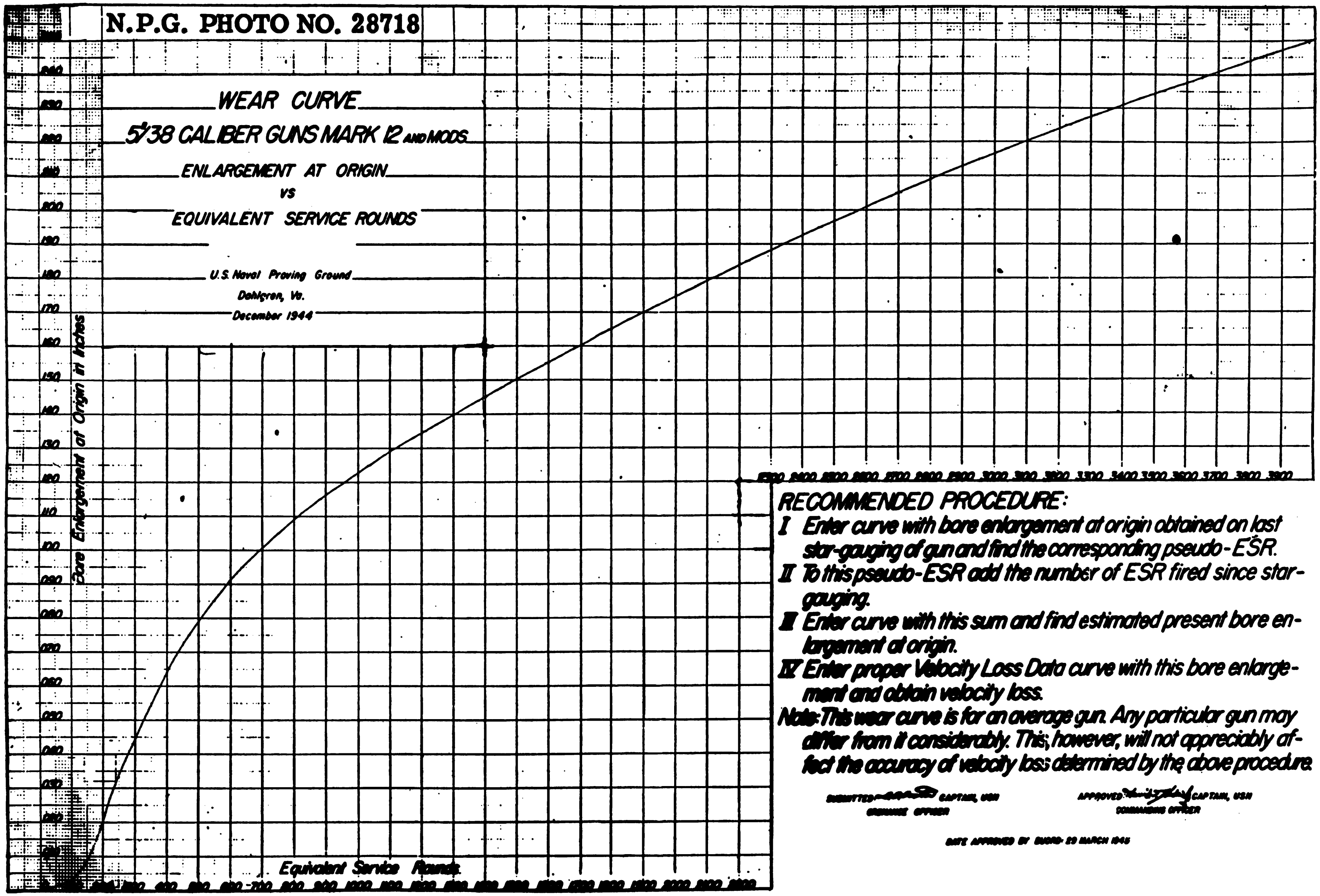
2. Velocity loss due to erosion is 171 f/s.

3. Total velocity loss is 171 + 21 = 192 f/s

U.S. Naval Proving Ground
Dahlgren, Va.
December 1944

Date approved by BuOrd:
29 March 1945

VELOCITY-LOSS DATA CURVES (Continued)



RECOMMENDED PROCEDURE:

I Enter curve with bore enlargement at origin obtained on last star-gauging of gun and find the corresponding pseudo-ESR.

II To this pseudo-ESR add the number of ESR fired since star-gauging.

III Enter curve with this sum and find estimated present bore enlargement at origin.

IV Enter proper Velocity Loss Data curve with this bore enlargement and obtain velocity loss.

Note: This wear curve is for an average gun. Any particular gun may differ from it considerably. This, however, will not appreciably affect the accuracy of velocity loss determined by the above procedure.

SUBMITTED: CAPTAIN, USN
ORDNANCE OFFICER

APPROVED: CAPTAIN, USN
COMMANDING OFFICER

DATE APPROVED BY BUORD: 29 MARCH 1945

Appendix D

TABLE OF NATURAL TRIGONOMETRIC FUNCTIONS

(Note: When entering tables with an angle larger than 45 select such angle from right hand side and obtain values in column corresponding to the function at *bottom* of page.)

Angle	Sin	Cos	Tan	Cot	Sec	Csc	
0°	.0000	1.0000	.0000	∞	1.000	∞	90°
1	.0174	.9998	.0175	57.29	1.000	57.30	89
2	.0349	.9994	.0349	28.64	1.001	28.65	88
3	.0523	.9986	.0524	19.08	1.001	19.11	87
4	.0698	.9976	.0699	14.30	1.002	14.34	86
5	.0872	.9962	.0875	11.43	1.004	11.47	85
6	.1045	.9945	.1051	9.514	1.006	9.567	84
7	.1219	.9925	.1228	8.144	1.008	8.206	83
8	.1392	.9903	.1405	7.115	1.010	7.185	82
9	.1564	.9877	.1584	6.314	1.012	6.392	81
10	.1736	.9848	.1763	5.671	1.015	5.759	80
11	.1908	.9816	.1944	5.145	1.019	5.241	79
12	.2079	.9781	.2126	4.705	1.022	4.810	78
13	.2250	.9744	.2309	4.331	1.026	4.445	77
14	.2419	.9703	.2493	4.011	1.031	4.134	76
15	.2588	.9659	.2679	3.732	1.035	3.864	75
16	.2756	.9613	.2867	3.487	1.040	3.628	74
17	.2924	.9563	.3057	3.271	1.046	3.420	73
18	.3090	.9511	.3249	3.078	1.051	3.236	72
19	.3256	.9455	.3443	2.904	1.058	3.072	71
20	.3420	.9397	.3640	2.747	1.064	2.924	70
21	.3584	.9336	.3839	2.605	1.071	2.790	69
22	.3746	.9272	.4040	2.475	1.079	2.669	68
23	.3907	.9205	.4245	2.356	1.086	2.559	67
24	.4067	.9135	.4452	2.246	1.095	2.459	66
25	.4226	.9063	.4663	2.145	1.103	2.366	65
26	.4384	.8988	.4877	2.050	1.113	2.281	64
27	.4540	.8910	.5095	1.963	1.122	2.203	63
28	.4695	.8829	.5317	1.881	1.133	2.130	62
29	.4848	.8746	.5543	1.804	1.143	2.063	61
30	.5000	.8660	.5774	1.732	1.155	2.000	60
31	.5150	.8572	.6009	1.664	1.167	1.942	59
32	.5299	.8480	.6249	1.600	1.179	1.887	58
33	.5446	.8387	.6494	1.540	1.192	1.836	57
34	.5592	.8290	.6745	1.483	1.206	1.788	56
35	.5736	.8192	.7002	1.428	1.221	1.743	55
36	.5878	.8090	.7265	1.376	1.236	1.701	54
37	.6018	.7986	.7536	1.327	1.252	1.662	53
38	.6157	.7880	.7813	1.280	1.269	1.624	52
39	.6293	.7771	.8098	1.235	1.287	1.589	51
40	.6428	.7660	.8391	1.192	1.305	1.556	50
41	.6561	.7547	.8693	1.150	1.325	1.524	49
42	.6691	.7431	.9004	1.111	1.346	1.494	48
43	.6820	.7314	.9325	1.072	1.367	1.466	47
44	.6947	.7193	.9657	1.036	1.390	1.440	46
45	.7071	.7071	1.0000	1.000	1.414	1.414	45
	Cos	Sin	Cot	Tan	Csc	Sec	Angle

Appendix E

FIRE CONTROL DEFINITIONS

E1. GENERAL DEFINITIONS

GUN-TARGET (GT) LINE is the line joining a ship delivering gunfire support and the target.

OBSERVER-TARGET (OT) LINE is the line joining the naval gunfire shore spotter and the target.

THE HORIZONTAL is a plane tangent to the earth's surface or parallel to such a plane.

A VERTICAL PLANE is a plane perpendicular to the horizontal. It may pass through any designated line or point.

A TRAVERSE PLANE is a plane determined by a point of aim and the elevation axis of the sight.

THE REFERENCE PLANE for a battery is an arbitrarily chosen plane, usually within the ship, from which angles of elevation of all battery elements are measured. In practice, it may be the plane containing one of the battery roller paths, or it may be an imaginary plane.

LEVEL ANGLE is the inclination of the battery reference plane with the horizontal, measured in a plane that contains the line of sight. The latter plane may be either the vertical or a plane perpendicular to the reference plane, depending on the design of the control equipment.

CROSSLEVEL ANGLE is the inclination of the battery reference plane with the horizontal, usually measured in a plane perpendicular to the plane in which level is measured. The latter plane may be either the vertical or a plane perpendicular to the reference plane, depending on the design of the control equipment.

TRUNNION TILT is the instantaneous inclination of the axis of the trunnions to the horizontal.

ROLL is the instantaneous value of the angle between the reference plane and the horizontal, measured in an athwartship vertical plane.

PITCH is the instantaneous value of the angle between the reference plane and the horizontal, measured in a fore-and-aft vertical plane.

NOTE: For purposes of naval gunnery both roll and pitch are measured and recorded as rates; that is, in terms of amplitude per unit time, ordinarily as total degrees of roll (or pitch) per minute.

STABILIZATION is the technique of correcting for deck inclination.

POINT OF AIM is that point on a target at which the sight is directed.

LINE OF SIGHT (LOS) is the straight line joining the sight and the point of aim.

AXIS OF THE BORE is the extension of the axis of the gun bore. It is tangent, at the muzzle, to the trajectory of a projectile fired from the gun.

LINE OF FIRE (LOF) is the straight line joining the gun and the point of impact (or burst) of the projectile. As used in safety precautions for target practices, the line of fire is assumed to include all points near the bearing of the line of fire.

TARGET ANGLE is the relative bearing of own ship from the target, measured in the horizontal from the bow of the target clockwise from 0 degrees to 360 degrees.

POSITION ANGLE is the vertical angle between the horizontal and the line of sight to an elevated target.

RELATIVE TARGET BEARING is the bearing of the target from the firing ship measured in the horizontal plane from the bow of own ship clockwise from 0 degrees to 360 degrees.

TRUE TARGET BEARING is the true bearing of the target from the firing ship.

GENERATED TARGET BEARING (RELATIVE or TRUE) is the relative or true bearing of the target as determined in a computing instrument from previous positions of own ship and target and established rate of change of bearing.

WIND DIRECTION is the direction *from* which the wind is blowing.

TRUE WIND is the wind as it exists with respect to the earth and independent of any motion of the ship.

APPARENT WIND is the wind apparent at the observing station, and is the resultant of the true wind and the motion of the observing station.

Parallax is the angular difference which results from making observations or computations to one target from two different stations. Train, or horizontal, parallax is the angular difference measured in the horizontal plane. Elevation, or vertical, parallax is the angular difference measured in the vertical plane.

Bearing Rate is the rate of change of target bearing from own ship caused by the relative motion of own ship and target. It may be expressed in knots (linear measure) or in degrees per minute (angular measure).

Range Rate is the rate of change of range in yards per minute caused by relative motion of own ship and target.

Elevation Rate is the rate of change of target elevation (position angle) in degrees per minute.

Angle of Climb or Dive is the vertical angle between the horizontal and the direction of motion of the target measured in degrees at the target.

Rate of Climb is the rate of change of altitude measured in feet per minute or in knots.

Loading Dead Time is the time between the instant a projectile is removed from the fuze pot and the instant of firing that projectile. For practical purposes, when firing mechanical-time-fuzed projectiles, the average loading dead time of the battery is the dead time for which correction must be made.

Sight Angle is the vertical component of the angle between the line of sight and the axis of the bore.

Gun Elevation is the vertical angle between the horizontal plane and the axis of the bore.

A Mil is a unit of angular measurement. It is equal to the angle whose tangent is 1/1,000, and is equivalent to 3.44 minutes or 3 minutes 26 seconds of arc. (The Army defines Mil as the angle subtended by an arc equal to 1/6,400th part of the circumference of a circle.)

Azimuth is the angle in mils (Army definition) measured from grid north to the OT line.

Gun Train Order is the signal transmitted to the guns indicating the angle in the reference plane from own ship's bow clockwise to the perpendicular plane through the axis of the bore.

Gun Elevation Order is the signal transmitted to the gun indicating the gun elevation above the deck plane measured in a plane through the bore axis perpendicular to the deck plane.

Range is the distance from a station on own ship to the target or some other designated point.

Slant Range is the distance to an aerial point or target.

Horizontal Range is the horizontal component of slant range.

Altitude is the vertical component of slant range. (Since this definition disregards the curvature of the earth, it should not be applied beyond the limits of present gun fire control systems.)

Present Range is the best available measurement of the range to the target.

Advance Range is present range combined with the corrections and predictions necessary to compensate for own-ship and target motion during the time of flight, plus ballistic corrections and spots.

Gun Range is the range listed in the range table corresponding to gun elevation.

Hitting Gun Range is gun range corrected for the error of MPI.

Navigational Range is the best distance to the target, used in post-firing analysis.

Ballistic Corrections are corrections in range and/or deflection to compensate for known or predicted errors, for drift, for wind, and for all variations from standard range-table conditions.

Initial Ballistic Correction is that part of the ballistic corrections not automatically compensated for by the fire control system.

Arbitrary Ballistic Correction is an empirical correction in range or deflection to compensate for all indeterminate errors in the fire control problem. It is obtained from an analysis of previous firings. This is commonly referred to as ACTH (arbitrary correction to hit).

Control Ballistic Corrections consist of the correction to the gun range and deflection to obtain the sight scale range and deflection.

Ballistic Wind is the effective wind, determined by computation, of such force and direction that its action on the projectile during the time of flight will be the same as the combined actions produced by the various true winds acting in the strata through which the projectile will pass as it moves along its trajectory.

Ballistic Range Wind is the horizontal component of the ballistic wind parallel to the target bearing.

Ballistic Cross Wind is the horizontal component of the ballistic wind at right angles to the target bearing.

Ballistic Density is the single air density, determined by computation, which would have the same range effect on the projectile as the actual densities throughout the trajectory.

Superelevation is the angle the gun must be elevated above the line of sight to compensate for the curvature of the trajectory caused by the force of gravity acting on the projectile.

Deflection is the lateral angular correction (converted to the deck plane where necessary) which is applied to the target bearing in the deck plane to obtain gun train order.

INITIAL VELOCITY is the velocity of the projectile at the instant the projectile leaves the gun.

NOMINAL INITIAL VELOCITY is the initial velocity assigned a new gun with the propellant at a temperature of 90° F.

RANGE-TABLE INITIAL VELOCITY is the initial velocity for which the range table is computed.

A SALVO consists of one shot or several shots fired simultaneously or nearly so by the same battery at the same target.

THE PATTERN of a salvo in range is the distance measured parallel to the line of fire between the shot of the salvo falling or bursting at the greatest distance from the firing point and the shot falling or bursting at the shortest distance, excluding wild shots. In deflection it is the distance measured at right angles to the line of fire between the shot falling or bursting at the greatest distance to the right and the shot falling or bursting at the greatest distance to the left, excluding wild shots.

THE MEAN POINT OF IMPACT (MPI) is the origin of a set of rectangular coordinates so located that the algebraic sums of the distances of the several impacts from the three axes are each equal to zero.

THE DISPERSION of a shot is the distance of the point of impact of that shot from the MPI of the salvo. Dispersion in range is measured parallel to the line of fire, and in deflection at right angles to the line of fire in a horizontal plane.

THE APPARENT MEAN DISPERSION of a salvo in range (or deflection) is the arithmetical average of the dispersion in range (or deflection) of the several shots of the salvo, excluding wild shots.

ERROR OF THE MEAN POINT OF IMPACT is the distance of the MPI from the target or other reference point, measured parallel to the line of fire for range and at right angles to the line of fire for deflection.

A STRADDLE is obtained from a salvo in range (or deflection) when, excluding wild shots, a portion of the shots of that salvo fall or detonate short and other shots of the salvo beyond the target (right and left, respectively, for deflection). (In naval gunfire support this may be known as a BRACKETING SALVO.)

A BRACKET is a succession of two salvos, one over and one short, or one right and one left, with no straddles.

A WILD SHOT is a shot with an abnormally large dispersion in range, or, in deflection, or in both.

THE DANGER SPACE for a material target is the distance in front of the target, measured parallel to the line of fire, that the target could be moved toward the firing point, so that a shot striking the base of the target in its original position would strike the top of the target in its new position.

THE HITTING SPACE for a material target is the distance measured parallel to the line of fire between a shot striking the top of the target and one striking the waterline on the engaged side of the target.

E2. CONTROL is authority, less than full command, exercised over the armament or a portion thereof.

A. SUPERVISORY CONTROL is the direction of the over-all employment of the vessel's armament. It is concerned with the disposition of the batteries to best meet existing conditions, the interior communications plan to be used, the selection and designation of targets for batteries or groups thereof, and the designation of standard procedure to be employed. Supervisory control is exercised by the Gunnery Officer, assisted by his Battery Officers, and by CIC Liaison Officers.

B. BATTERY CONTROL is the direction of the employment of all the mounts or turrets of a similar caliber or purpose in a vessel. It is concerned with the disposition of the mounts or turrets with respect to the fire control stations of the battery, the interior communications plan to be used, the designation and acquisition of targets by the battery or group, and the standard procedures to be employed. The Battery Control Officer is assisted by Group and Sector Control Officers, and by CIC Liaison Officers.

1. BATTERY CONTROL is classified as to TYPE by the manner in which the command of the battery is exercised.

   a. COLLECTIVE BATTERY CONTROL is that type of battery control in which the direction of the employment of the battery is centralized. (This type of control may leave a primary director unemployed, and the latter will be considered in STAND-BY CONTROL.)

   b. DISPERSED BATTERY CONTROL is that type of battery control in which the direction of the employment is decentralized.

      (1) DIVIDED BATTERY CONTROL is that form of dispersed control wherein a battery with two directors is divided into forward and after batteries for command purposes. This form of control is associated with centerline, single-purpose batteries.

      (2) SECTOR BATTERY CONTROL is that form of dispersed control in which a battery with multiple directors is divided into sectors for control purposes. This form of control is associated with dual-purpose and automatic weapon batteries.

2. BATTERY CONTROL as to METHOD prescribes the grouping of the mounts or turrets with fire control stations, command communications channels between fire control stations, and procedures for designation and acquisition. For a particular vessel the groupings are prescribed in the battle bill.

C. GROUP CONTROL is the control of a specified group of a battery. It is concerned with the type and method of fire control, the procedures to be employed, and the acquisition and destruction of designated targets, as well as the detection of undesignated targets appearing in the assigned sector of fire. Group Control is exercised by the Group Control Officer, assisted by Director Officers, Mount Captains or Turret Officers, and CIC Liaison Officers.

D. SECTOR CONTROL is the control of one group of a battery, or two or more groups of different batteries, each of which is assigned the same sector of fire. It is concerned with the acquisition and destruction of designated targets appearing in the sector. Sector Control is exercised by the Sector Control Officer, assisted by Group Control Officers, and CIC Liaison Officers.

E. The organized system by means of which the offensive power of armament is controlled is known as FIRE CONTROL.

1. FIRE CONTROL is classified as to TYPE by the system employed. For each type of fire control the battle bill of the vessel specifies the instruments to be employed.

a. PRIMARY FIRE CONTROL prescribes the utilization of the principal system. This is the system provided to control before damage occurs to this system.

b. SECONDARY FIRE CONTROL prescribes the utilization of an alternate system to give greater flexibility of control.

c. AUXILIARY FIRE CONTROL prescribes the utilization of a system provided solely to substitute for a primary system in case of damage.

d. LOCAL FIRE CONTROL provides for the control of a single gun mount or a turret from a local station in or adjacent to the mount or turret.

2. FIRE CONTROL is classified as to METHOD by the procedures employed in the direction of the fire of the battery.

a. DIRECT FIRE CONTROL is the control procedure employed when the target is observed from the firing vessel visually or by radar.

b. INDIRECT FIRE CONTROL is the control procedure employed when the target is unobserved by the fire control instruments of the firing vessel.

c. OFFSET FIRE CONTROL is the control procedure employed when a point of aim of known relationship to the target is observed from the firing vessel.

E3. TARGET INDICATION is a manifestation, to Command and Control, of targets approaching into or appearing in the area of gunfire. It includes all information available for proper designation, including the presence, identity, location, size, number, course, speed, and estimate of intent, plus any additional evaluated factors which are necessary for proper designation.

A. TARGET INDICATION is classified as to TYPE by the means by which target presence is manifested.

1. RADAR INDICATION prescribes manifestation of target presence by radar.

2. VISUAL INDICATION prescribes manifestation of target presence by visual sighting.

B. TARGET INDICATION is classified as to METHOD by the system employed to display target presence.

1. AUTOMATIC INDICATION is indication of targets by means of an electromechanical system capable of indicating in one display all targets appearing in the area under investigation.

2. MANUAL INDICATION is the indication of targets by means of a manual plot of all targets observed or reported in the area under investigation.

E4. TARGET DESIGNATION is the selection of the targets which are to be taken under fire, and transmission of the requisite information for acquisition to the selected fire control station or stations.

A. TARGET DESIGNATION is classified as to TYPE by the station originating the designation.

1. COMMAND DESIGNATION is the designation of a target by a command station.

a. OTC designating vessel to take target under fire.
b. CO of vessel designating target to be taken under fire.

2. CONTROL DESIGNATION is the designation of a target from a fire control station.

3. LOCAL DESIGNATION is the designation of a target by mount or turret personnel.

B. TARGET DESIGNATION is classified as to METHOD by the procedure employed for designation.

1. AUTOMATIC DESIGNATION is the designation of the target by means of instruments which transmit sufficient data to the selected gun fire control system to result in target acquisition.

2. PARTIAL AUTOMATIC DESIGNATION is the designation of the target by means of a partially automatic system which must be aided by coaching in order that the selected director will be positioned to acquire the target.

3. VERBAL DESIGNATION is the designation of the target by voice or telephone.

E5. TARGET ACQUISITION is the process of positioning the tracking apparatus of a control system so that a designated target is gated in the radar or fixed in the optics or open sights.

E6. AIMING is the process of establishing target position in bearing and elevation.

A. AIM is classified as to TYPE by the instrument employed:

1. RADAR AIM prescribes determination of target bearing and elevation by radar.

a. PARTIAL RADAR AIM prescribes determination of bearing by radar and determination of elevation by stabilizing equipment.

2. OPTICAL AIM prescribes determination of target bearing and elevation by optical instruments.

a. PARTIAL OPTICAL AIM prescribes determination of target bearing by optical instrument and elevation by means of stabilizing equipment.

3. GENERATED AIM prescribes the generation of target bearing and elevation, and corrections thereto for deck inclination, by means of a computer and stabilizing equipment.

B. AIM is classified as to METHOD by the manner in which the aiming system is operated.

1. CONTINUOUS AIM prescribes continuous measurement of target position in bearing and elevation.

a. CONTINUOUS AUTOMATIC AIM prescribes automatic continuous aiming with the aiming instrument.

b. CONTINUOUS AIDED AIM prescribes continuous aiming with the aiming instrument positioned by signals received from the computer and with the resulting position corrected by the operators.

c. CONTINUOUS MANUAL AIM prescribes continuous aiming with the aiming instrument positioned by hand, using either direct manual drive or local power.

2. INTERMITTENT AIM prescribes periodic measurement of target position in one element and continuous measurement in the other.

a. SELECTED ELEVATION prescribes determination of target position continuously in bearing and intermittently in elevation.

b. SELECTED TRAIN prescribes determination of target position continuously in elevation and intermittently in train.

E7. RANGING is the process of establishing target distance from the firing ship.

A. RANGING is classified as to MEANS by the instrument employed:

1. RADAR RANGING prescribes determination of target distance by radar.

2. OPTICAL RANGING prescribes determination of target distance by rangefinder.

3. GENERATED RANGING prescribes the generation of target distance by a computer.

4. ESTIMATE RANGING prescribes the determination of target distance by estimation.

5. NAVIGATIONAL RANGING prescribes the determination of target distance by navigational means.

B. RANGING is classified as to TYPE by the frequency with which the range is established.

1. CONTINUOUS RANGING is that type of ranging in which target distance is continuously established.

2. INTERMITTENT RANGING is that type of ranging in which target distance is established at intervals.

C. RANGING is classified as to METHOD by the procedure employed to operate the instrument.

1. MANUAL RANGING is that method of ranging in which the ranging instrument is operated by hand.

2. AIDED RANGING is that method of ranging in which the generated change of range is introduced into the ranging instrument and upon which corrections are superimposed manually by the rangefinder or radar operators, as required.

3. AUTOMATIC RANGING is that method of ranging in which the ranging instrument automatically determines target distance of an acquired target.

E8. TRACKING is the process of establishing the path of target motion with respect to the firing ship and is accomplished by combining the data obtained by the aiming and ranging processes.

A. TRACKING is classified as to TYPE by the form of tracking employed.

1. DIRECT TRACKING is that type of tracking in which target path is established by direct observation (radar or optical).

2. INDIRECT TRACKING is that type of tracking in which the range, bearing, and elevation of the target are generated by the computer and its associated equipment.

3. OFFSET TRACKING is that type of tracking in which the target path is established by the direct observation of an intermediate point of aim in known relationship to the designated target.

B. TRACKING is classified as to METHOD by the manner in which the computers are employed to determine the th of target motion.

1. AUTOMATIC TRACKING is that method of tracking in which the target path is established by use of radar for aiming and ranging and without manual operation of any of the tracking controls in the fire control system.

2. AUTOMATIC LEAD COMPUTING is that method of tracking in which the process of aiming automatically generates a solution of target motion. This method of tracking is associated with instruments using gyros to measure the angular velocity of the LOS.

3. RATE CONTROL is that method of tracking in which the computer's generated path of estimated target motion is made to coincide with the observed path of target motion by comparing the observed and generated rates of motion.

a. AUTOMATIC RATE CONTROL is that method of rate controlling in which the generated target motion is automatically corrected to agree with the observed target motion by a rate-control mechanism operated by the director operators.

b. SEMIAUTOMATIC RATE CONTROL is that method of rate controlling in which the generated target motion is automatically corrected to agree with the observed target motion by a rate control mechanism operated by the computer operators.

c. MANUAL RATE CONTROL is that method of rate controlling in which the generated target motion is corrected to agree with observed target motion by changes to target course, speed, and angle of climb introduced manually by the computer operators.

E9. PREDICTING is the process of determining future target position. Predicting operations are accomplished in computers simultaneously and automatically with tracking.

E10. GUN LAYING is the process of positioning guns in train and elevation in a predetermined relationship with respect to the line of sight. The line of sight may be established at an aloft director or generated in the plotting room, or it may be established at the gun.

A. GUN LAYING is classified as to TYPE by the manner in which guns are positioned:

1. CONTINUOUS GUN LAYING. Guns are positioned continuously in accordance with the computed signals and loaded at any position.

2. INTERMITTENT GUN LAYING. Guns are positioned when loaded, but must be returned to a specified position after firing for loading.

B. GUN LAYING is classified as to METHOD by the means by which guns are positioned.

1. AUTOMATIC GUN LAYING. Guns are positioned automatically by remote control systems in accordance with signals received.

2. INDICATOR GUN LAYING. Guns are positioned locally in accordance with signals received. Positioning may be effected by either local power or manual drive.

3. LOCAL GUN LAYING. Guns are positioned locally by gun-sight telescope. Positioning may be effected by either local power or manual drive.

E11. GUN FIRING is the process of shooting a gun or guns.

A. GUN FIRING is classified as to MEANS by the firing system employed.

1. ELECTRIC FIRING provides for the shooting of a gun by an electrical system controlled by either:

a. LOCAL KEY provides for firing by means of a key actuated at the gun mount or turret.

b. MASTER KEY provides for firing by means of a key actuated at a station remote from the mounts or turrets, such as a director or control station.

(1) AUTOMATIC KEY is a form of master key firing in which an automatic contact maker is employed to fire at a selected firing point.

2. PERCUSSION FIRING provides for the shooting of guns by mechanical firing mechanism at the gun mount or turret.

B. GUN FIRING is classified as to TYPE by the rate at which guns are shot.

1. RAPID FIRE is that type of fire in which no check fire is used for purposes of applying corrections.

2. Slow Fire is that type of fire in which the fire is deliberately delayed to allow for the application of corrections or to conserve ammunition.

3. Deliberate Fire is that type of slow fire which is executed on a prearranged time schedule.

C. Gun Firing is classified as to method by the manner in which individual guns are shot with respect to the other guns of the battery.

1. Salvo Fire is the simultaneous firing of all guns ready and aimed at the same target.

2. Full Salvo Fire is the simultaneous firing of all guns of a group.

3. Split Salvo Fire is the firing of less than the full number of guns in a multiple gun mount or mounts at a given instant.

4. Partial Salvo Fire is the firing of less than the full number of mounts or turrets (in multiple gun-mount batteries) at a given instant.

5. Continuous Fire is the firing of each gun without regard for the readiness of other guns of the battery.

E12. SPOTTING is the estimation of the required correction of range, elevation, deflection, and fuze range to hit the target. The Spotter is the person actually observing the fall of shot or burst and making the estimates of required corrections. A Spot is the correction estimated by the spotter.

A. Spotting is classified as to means by the station from which the observation is made:

1. Ship Spot indicates that the spotter is stationed in the firing ship at a designated spotting station.

2. Local Spot indicates that the spotter is stationed in the firing ship at or adjacent to a mount or turret.

3. Shore Spot indicates that the spotter is stationed ashore.

4. Air Spot indicates that the spotter is stationed in an aircraft or airship.

B. Spotting is classified as to type by the manner in which observations are made:

1. Visual:

a. Eye Spotting is the term used to indicate observations made by eye without the use of optical instruments.

b. Optical Spotting is the term used to indicate that observation is assisted by optical aids, including ordinary binoculars, spotting binoculars fitted with mil scales, spotting glasses, or stereoscopic range finders.

2. Radar:

a. Radar Spotting is the term used to indicate that the observation is made by radar.

C. Spotting is classified as to method by the manner of estimating the error of burst or impact.

1. Direct Spotting is that method in which the spotter's correction is based on his estimate of the error of the mean point of impact from the target. A direct spot may be made on the fall of shot of one salvo or as the result of an observation of an initial ladder.

2. Bracket and Halving is a method used in visual spotting at extremely long ranges, from low spotting stations, or with poor illumination, when the spotter can determine whether the shots are short or over, but the amount of error cannot be estimated with reasonable accuracy. On observing the initial fall of shot, a spot is made which is believed to be sufficiently large to ensure crossing the target. If the next salvo crosses the target, the following spot is applied in the opposite direction (towards the target) but is half the amount of the initial spot. Successive spots are in the same direction until the target is crossed again. When this occurs, the direction of the spots is again reversed and again halved. The process is continued until the target is located within the pattern.

E13. LADDERS are a succession of salvos fired with known and predetermined changes between successive salvos, to ensure early establishment of hitting gun range and deflection in surface fire, to serve as a yardstick for covering an area target, or to increase pattern size.

A. Ladders are classified as to type by the element in which laddering takes place.

1. Deflection Ladders are ladders fired with predetermined changes in deflection on successive salvos. They are seldom used in our Navy, except for covering area targets or in radar spotting when the discrimination of fire control radar makes a deflection rocking ladder advisable.

2. Range Ladders are ladders fired with predetermined changes in range on successive salvos.

3. Elevation Ladders are ladders fired with predetermined changes in elevation between successive salvos. They are seldom used in our Navy.

B. Ladders are classified as to method by the manner in which the predetermined arbitrary corrections are introduced.

1. INITIAL LADDERS are ladders in which, in addition to known increments or steps, the number of salvos is definitely known. This number is greater than two, and the steps are sufficiently large, so that the target will be located within the limits of the ladder.

2. ADD LADDERS are fired with the initial gun range less than the best range and with successive steps of the ladder fired with increasing ranges, each increasing range spot not less than the pattern size.

3. DROP LADDERS are fired with the initial gun range greater than the best range and with successive steps of the ladder fired with decreasing ranges, each decreasing range spot not less than the pattern size.

4. CONTINUOUS LADDERS are fired with a continuous application of spots, applied in such a manner as to move the salvos back and forth across the target.

a. SPOTTER-CONTROLLED LADDER is a form of continuous ladder in which the spotter or observer determines all or part of initial direction, when to change direction, size of first ladder steps, and when the ladder is reversed. For simplicity, the size of steps of the first ladder and successive ladders is usually prearranged. The initial correction of the first ladder may be directed by doctrine or other orders.

b. ROCKING LADDER is a form of continuous ladder in which the number of steps of the ladder before reversal of direction and the size of the steps are both specified beforehand. The object is to increase the pattern size and still maintain sufficient projectile density to ensure hits. The steps of the ladder are never larger than the pattern size, and the number of steps is such as will ensure covering probable ranging and aiming errors and target maneuvers during time of flight. If used with continuous fire the steps are applied at regular predetermined time intervals; if with salvo fire, after each salvo.

E14. BARRAGES are a barrier of fire executed on predetermined firing data. The initial shots are placed across the probable path of the target.

A. BARRAGES are classified as to METHOD by the manner in which position of the bursts is varied.

1. LINE-OF-SIGHT BARRAGE is a barrage using fixed fuze setting and varying sight settings, with each shot so directed that bursts will occur in the instantaneous line of sight to the target.

2. FIXED-ZONE BARRAGE is a barrage fired with fixed sight settings. Once the target has passed through the zone of fire, a second zone may be selected and a new barrage fired.

3. CREEPING-ZONE BARRAGE is a barrage in which the fuze settings are varied in such a way as to advance along the track at a rate slower than that of the actual target advance.

Appendix F

STANDARD FIRE CONTROL SYMBOLS

F1. General

Symbols are used in fire control to provide a brief, accurate means of representing quantities which would otherwise require extended definition. The standard system of fire control symbols approved by the Bureau of Ordnance is applicable to the surface and antiaircraft problems and, with certain exceptions, to the torpedo fire control problem and the antisubmarine fire control problem. Standard symbols used in the torpedo fire control problem are listed in chapter 27.

Method of forming symbols. The fire control symbols are made up of capital letters, standing for basic quantities, and lower case letters, arabic numerals, the Greek letter Δ, and the prime (′) used as modifying symbols. For example, So is made up of a basic symbol S meaning, "speed" and a modifying symbol, o meaning, "of own ship." Hence, the symbol So signifies own ship's speed.

One basic symbol may be modified simultaneously by a number of modifying symbols, and in certain unusual cases by another basic symbol used as a modifier. Thus, B, bearing, can be modified first to become Br, relative bearing, then further to cBr, generated relative bearing, and finally to ΔcBr, increments of generated relative bearing. As is apparent in this example, modifiers added ahead of an already modified quantity normally act to modify that quantity further; when, however, additional modifying symbols are added after a basic quantity they may have similar effect, or they may in certain cases be additive in effect, thus $Rj + Rt + Rw + Rm + Rx$ may be written $Rjtwmx$.

To illustrate the use of the prime, B is the basic symbol for bearing. Unmodified, it means true bearing, measured from a vertical plane through the north-south axis to a vertical plane through the line of sight to the target, in the horizontal plane clockwise from north. (Note that to define an angle completely, it is necessary to indicate [1] from what plane it is measured, [2] to what plane it is measured, and [3] in what plane it is measured.) Br, relative target bearing, is measured from a vertical plane through the fore-and-aft axis of own ship from the bow of own ship to a vertical plane through the line of sight, in the horizontal plane clockwise from the bow of own ship. Since guns and directors are fastened to the deck of the ship, they can measure Br only at that instant when the deck is horizontal. Consequently, actual values of director train (an angle measured in the deck plane is called, in fire control language, *train* not *bearing*) include a prime (′) signifying that the quantity is measured with respect to the standard reference plane of the ship, or deck plane. $B'r$, director train, is the quantity actually used in some dual-purpose fire control systems, and is the angle measured from the vertical plane through the fore-and-aft axis of own ship to the vertical plane through the line of sight, in the deck plane clockwise from the bow of own ship. This measurement is possible only in systems which have stabilization of the director optics, so that the crosswires of the telescopes are maintained in the vertical and horizontal. If this is not the case, director train is measured with respect to director sights which elevate in a plane perpendicular to the deck, and the symbol is $B'r'$, the first prime indicating "in the deck plane," the second prime indicating "perpendicular to the deck plane." In the same way, E is elevation measured in a vertical plane and E′ is elevation measured in a plane perpendicular to the deck.

F2. Basic symbols and definitions

Symbol	*Definition*
A	Target angle.
B	Bearing (of target, unless modified), measured in the horizontal plane.
C	Course, measured in the horizontal plane.
D	Lateral deflection (angular measure).
E	Elevation (of target, unless modified), measured in the vertical plane.
F	Fuze setting.
G	Gyro angle (torpedoes).

Symbol	*Definition*
H	Height of target (normally in feet).
I	Angle of climb or dive (inclination).
K	(Also $K1$, $K2$, *etc.*) Constants.
L	Level angle, measured in the vertical plane.
M	Roll.
N	Pitch.
P	Parallax.
Q	Spread gyro angle (torpedoes).
R	Range.
S	Speed.
T	Time.
U	Average projectile velocity.
V	Elevation prediction. (Angular measure.)
W	Wind.
X	Horizontal deflection component of velocity perpendicular to the vertical plane through the line of sight.
Y	Horizontal range component of velocity in the vertical plane through the line of sight.
Z	Crosslevel angle.

F3. Common modifying symbols and definitions

Symbol	*Definition*
a	Of torpedo.
b	Of director.
c	Before a quantity means the value of that quantity as generated by the mechanism, as opposed to the observed value of the same quantity. After a quantity means relative to rate control.
d	Before a quantity means a time rate of change of that quantity. After a quantity means in or relative to the deck plane or plane perpendicular to the deck.
e	Elevation.
f	Due to standard trajectory.
g	Of gun.
h	Horizontal projection of.
i	Searchlight (illumination).
j	Before a quantity means a correction or partial correction to that quantity, usually generated by the mechanism. After a quantity means arbitrary correction (spot) to that quantity.
m	Change of initial velocity.
o	Own ship; of or due to.
p	Parallax; of or due to.
q	Relative to the line of sound (ASW term).
r	Relative to own ship.
s	Relative to the line of sight, or in a slant plane. (Since several slant planes may be used, each definition specifies the plane used.)
t	Of or due to target.
u	Of torpedo tube.
v	Vertical projection of.
w	Of or due to wind.
z	Of or due to crosslevel.
$f(\ )$	Function of the quantity in parentheses.
Δ	Before a quantity means change in that quantity during some specific time. Increment of a quantity.
$'$	Indicates that a quantity is measured in or with respect to the deck plane.
2	After a quantity indicates that it is the predicted value of that quantity for advance position, *i. e.*, for the position at time of flight seconds after firing, or at time of impact or burst.
3	After a quantity indicates that it is the predicted value of that quantity for the time of the burst, of a fuzed projectile, the fuze having been set dead time seconds before firing.

NOTE: In definitions when the terms "deck plane" or "plane of the deck" are used, the standard reference plane of the ship is meant.

F4. Principal fire control quantities

A	*Target angle.* The angle between a vertical plane through the direction of target motion and the vertical plane through line of sight, measured in the horizontal plane clockwise from the direction of target motion.
B	*True target bearing.* The angle between a north- and south-vertical plane and the vertical plane through the line of sight, measured in a *horizontal plane* clockwise from the north.
$B'gr$	*Gun train order.* The ordered angle between the fore- and aft axis of own ship and a plane through the gun axis perpendicular to the deck plane, measured in the deck plane clockwise from the bow of own ship, without parallax correction.
Br	*Relative target bearing.* The angle between the vertical plane through the fore-and-aft axis of own ship and the vertical plane through the line of sight, measured in a horizontal plane clockwise from the bow of own ship.
$B'r$	*Director train* (*stabilized sight*). The angle between the vertical plane through fore-and-aft axis of own ship and the vertical plane through the line of sight, measured in the deck plane clockwise from the bow of own ship.

Symbol	Definition
$B'r'$	*Director train* (*sight not stabilized*). The angle between the fore-and-aft axis of own ship and the plane through the line of sight perpendicular to the deck plane, measured in the deck plane clockwise from the bow of own ship.
Bw	*True direction true wind.* The angle between north and the direction from which the true wind is blowing, measured in a horizontal plane clockwise from north.
Bwg	*Predicted wind angle.* The angle between the direction from which the wind is blowing and the vertical plane through the line of fire, measured in the horizontal plane clockwise from the direction from which the wind is blowing.
Bws	*Wind angle.* The angle between the direction from which the wind is blowing and the vertical plane through the line of sight, measured in the horizontal plane clockwise from the direction from which the wind is blowing.
Co	*Own-ship course.* The angle between the north- and south-vertical plane and the vertical plane through the fore-and-aft axis of own ship, measured in a horizontal plane clockwise from north.
Ct	*Target course.* The angle between the north-and-south vertical plane and the vertical plane through the direction of motion of the target, measured in a horizontal plane clockwise from north.
Cw	$Bw-180^\circ$. The angle between north and the direction toward which the true wind is blowing, measured in a horizontal plane clockwise toward north.
Cws	*Wind angle.* The angle between the direction toward which the wind is blowing and the vertical plane through the line of sight away from own ship, measured clockwise in a horizontal plane.
cB	*Generated true target bearing.* (See definition of B.)
ΔcB	*Increments of generated true target bearing.*
cBr	*Generated relative target bearing.* (See Br.)
ΔcBr	*Increments of generated relative target bearing.*
$cB'r$	*Generated director train* (*stabilized sight*). (See $B'r$.)
$\Delta cB'r$	*Increments of generated director train* (*stabilized sight*).
$cB'r'$	*Generated director train* (*sight not stabilized*). (See $B'r'$.)
$\Delta cB'r'$	*Increments of generated director train* (*Bearing correction*).
cE	*Generated target elevation.* (See E.)
ΔcE	*Increments of generated target elevation.*
ΔcEb	*Increments of generated director elevation.* $\Delta cEb=\Delta cE+L$.
cR	*Generated present range.*
ΔcR	*Increments of generated present range.*
Dd	*Deck deflection* (*stabilized sight*). The angle representing total deflection in the deck plane; it is added to director train to obtain gun train order, $B'gr$. $Dd+B'r=B'gr$ and $Dd=jDd+Dz$.
Dd'	*Deck deflection* (*sight not stabilized*). Angle representing total deflection in deck plane; it is added to director train to obtain gun train order, $B'gr$. $Dd'=Ds+Dz$.
Df	*Drift correction.* Deflection to compensate for drift of projectile, measured in the horizontal plane.
Dfs	*Drift correction.* The lateral deflection angle to compensate for drift of a projectile, measured in the slant plane through the predicted target position.
Dj	*Deflection spot.*
Ds	*Sight deflection.* Computed angle between vertical plane through line of sight and vertical plane through gun axis (neglecting parallax), measured in the horizontal or slant plane depending on system used.
Dt	*Relative motion deflection prediction.* Deflection prediction to compensate for relative motion of own ship and target during time of flight.
Dw	*Wind deflection prediction.* Deflection prediction to compensate for the effect of apparent wind on the projectile.
Dz	*Trunnion tilt train correction.* Approximate correction in gun train order to compensate for tilting of gun trunnions in cross-level.
dBr	*Angular bearing rate.* In the horizontal plane. The time rate of change of relative target bearing.
dBs	*Angular bearing rate in slant plane.* The time rate of change of target bearing measured in the slant plane through the line of sight.
dE	*Angular elevation rate.* The time rate of change of target elevation.
dH	*Rate of climb.* The time rate of change of target height.
dR	*Range rate.* The time rate of change of range.
dRh	*Horizontal range rate.* The time rate of change of horizontal range.

Symbol	*Definition*
dRm	Alteration to prediction range rate to compensate for changes in I. V.
dRs	*Prediction range rate.* Direct range rate corrected for the effect of deflection and elevation rates, and for changes in I. V.
dRxe	*Range rate correction.* Correction to prediction range rate for the effect of the deflection and elevation rates.
E	*Target elevation (stabilized sight).* The angle between the horizontal plane and the line of sight, measured in the vertical plane through the line of sight. $E = Eb - L$.
E'	*Target elevation (sight not stabilized).* The elevation above the horizontal of the line of sight, measured in the plane perpendicular to the deck, through the line of sight.
Eb	*Director elevation (stabilized sight).* The elevation of the director line of sight above the deck, measured in the vertical plane through the line of sight.
E'b	*Director elevation (sight not stabilized).* The elevation of the director line of sight above the deck, measured in a plane perpendicular to the deck, through the line of sight.
Eg	*Vertical gun elevation.* The elevation of the gun above the horizontal, measured in a vertical plane through the gun axis.
E'g	*Gun elevation order.* Ordered elevation of the gun above the deck plane, measured in a plane through the gun axis perpendicular to the deck plane.
E2	Predicted target elevation.
F	*Fuze setting order.* Fuze setting in seconds.
H	*Target height.* Vertical distance between the target and the horizontal plane through the director sights.
jB	Initial or corrective setting to generated target bearing.
jBc	*Linear deflection rate correction.* Rate control correction affecting linear deflection rate.
jB'r	Correction to director train for effect of deck tilt. (Refers director train to the horizontal plane, sight stabilized.)
jB'r'	Correction to director train for effect of deck tilt. (Refers director train to the horizontal plane, sight not stabilized.)
jDd	*Partial deck deflection.* An intermediate value used in computing *Dd*.
jE	Initial or corrective setting of generated target elevation.
jEc	*Linear elevation rate correction.* Rate control correction primarily affecting linear elevation rate.
jdR	*Direct range rate correction.* The rate control correction primarily affecting range rate.
jdRh	*Horizontal range rate correction.* Rate control correction primarily affecting horizontal range rate.
jHc	*Rate-of-climb correction.* Rate control correction primarily affecting rate of climb.
jR	*Initial or corrective setting of generated range.*
jRc	*Linear range correction.* Applied to generated range.
jRm	Partial range prediction to compensate for changes of initial velocity.
jRx	Partial range prediction to compensate for deflection exclusive of drift.
jVs	*Partial sight angle.* (Cam output.)
L	*Level angle.* The angle between the horizontal plane and the deck plane, measured in the vertical plane through the line of sight about an axis in the horizontal plane. (Positive when the deck toward the target is below the horizontal plane.)
L'	*Level angle.* The angle between the horizontal plane and the deck plane measured in the plane perpendicular to the deck through the line of sight about an axis in the deck. (Positive when the deck toward the target is below the horizontal plane.)
Lj	*Selected level angle.* Any arbitrary selected value of level (for those systems in which the directors measure level as *L*.)
L'j	*Selected level angle.* Any arbitrary selected value of level (for those systems in which the directors measure level as *L'*.)
M	*Roll.* The instantaneous value of the angle between the reference plane and the horizontal, measured in an athwartship vertical plane.
N	*Pitch.* The instantaneous value of the angle between the reference plane and the horizontal, measured in a fore-and-aft vertical plane,
Pe	Elevation parallax correction for vertical base. (In main-battery systems *Pv* is used for this quantity.)
Ph	Train parallax correction for horizontal base.
Pv	Elevation parallax correction for horizontal base. (See note on *Pe* above.)
R	*Observed present range.*

Symbol	*Definition*
RdBs	*Linear deflection (bearing) rate.* The horizontal component of relative motion between target and own ship, at right angles to the vertical plane through the line of sight.
RdE	*Linear elevation rate.* The component of relative motion between target and own ship, at right angles to the line of sight and in the vertical plane through the line of sight.
Rh	*Horizontal range.* The projection of the range on a horizontal plane.
Rj	*Range spot.*
Rm	Range prediction to compensate for changes in I. V.
Rt	Range prediction to compensate for relative motion of own ship and target.
Rtg	Correction in fuze range for dead time.
Rw	Range prediction to compensate for effect of apparent wind on projectile.
Rx	Range prediction to compensate for deflection exclusive of drift.
R2	*Advance range* (or predicted range).
R3	*Fuze range. R2—Rtg.*
S	*Target speed.* (Note: For an air target this represents the speed of an air target along a line of flight with respect to the earth.)
Sh	*Target horizontal ground speed.* The horizontal component of air target speed with respect to the earth.
So	*Own-ship speed.* The speed of own ship relative to the earth.
Ss	*Diving speed of target.* Speed along the line sight, or direct range rate.
Sw	*True wind speed.* The horizontal velocity of wind with respect to the earth.
T	*Time.* Generated by the regulated time motor.
Tf	*Time of flight.*
Tg	*Dead time.* Time in seconds between the setting of the fuze and the firing of the projectile.
V	*Total elevation prediction.* The approximate amount that target elevation changes during the time of flight. $V = Vtw - Vx + Vj$.
Vf	*Superelevation.* The angle the gun must be elevated above the predicted line of sight to compensate for the curvature of trajectory in the vertical plane.
Vfm	Correction to superelevation for a change in I. V.
Vj	*Elevation spot.*
Vs	*Sight angle.* The angle, computed in a vertical plane, which the gun must be elevated above the line of sight or the horizontal (depending on the system) in order to hit the target when the deck is horizontal. (A correction to *Vs* is needed to hit the target when the trunnions are tilted.)
Vt	*Relative motion elevation prediction.* Compensates for the relative motion of own ship and target during the time of flight.
Vw	*Wind elevation prediction.* Compensates for the effect of apparent wind on the projectile.
Vx	*Complementary error correction.* Correction to elevation prediction to compensate for deflection prediction.
Vz	*Trunnion tilt elevation correction.* Correction to gun elevation to compensate for the effect of crosslevel.
WrD	*Deflection wind rate.* The component of apparent wind velocity affecting deflection prediction.
WrE	*Elevation wind rate.* The component of apparent wind velocity affecting elevation prediction.
WrR	*Range wind rate.* The component of apparent wind velocity affecting range prediction.
Xo	Horizontal component of own-ship velocity at right angles to the vertical plane through the line of sight. (Deflection component.)
Xt	Horizontal component of target velocity at right angles to the vertical plane through the line of sight. (Deflection component.)
Xw	Component of true wind velocity across line of sight.
Xwg	Horizontal component of true wind velocity, at right angles to the vertical plane through the line of fire. (Deflection component.)
Xwgr	Horizontal component of apparent wind velocity, across the vertical plane through the line of fire. (Deflection component.)
Xwr	Component of apparent wind velocity across line of sight.
Yo	Horizontal component of own-ship velocity in the vertical plane through the line of sight. (Horizontal range component.)
Yt	Horizontal component of target velocity in the vertical plane through the line of sight. (Horizontal range component.)

Symbol	*Definition*
Yw	Component of true wind velocity along line of sight.
Ywg	Horizontal component of true wind velocity, in the vertical plane through the line of fire. (Horizontal range component.)
Ywgr	Horizontal component of apparent wind velocity, in the vertical plane through the line of fire. (Horizontal range component.)
Ywr	Component of apparent wind velocity along line of sight.
Zd	*Crosslevel angle.* Crosslevel angle measured about an axis in the deck; the angle, measured about the intersection of the plane of the deck with the vertical plane through the line of sight, between the vertical plane and a plane perpendicular to the deck through this axis. (Positive if when you face the target the right-hand side of the ship is up.)
Zdj	*Selected crosslevel angle.* Any arbitrary value of crosslevel when crosslevel is measured as indicated in the main symbol.
Zh	*Crosslevel angle.* Crosslevel angle measured about an axis in the horizontal; the angle, measured about the intersection of the horizontal plane with the vertical plane through the line of sight, between the vertical plane and a plane perpendicular to the deck through this axis. (Positive if when you face the target the right-hand side of the ship is up.)
Zhj	*Selected crosslevel angle.* Any arbitrary value of crosslevel when crosslevel is measured as indicated in the main symbol.

Appendix G

BUREAU OF ORDNANCE FUNCTIONS AND CONTROLS

G1. Bureau organization

Figure G1 shows the general organization of the Bureau of Ordnance. The paragraphs below outline very briefly the functions and responsibilities of the individuals and groups mentioned on the chart.

Chief of the Bureau. Within the limits established by *Navy Regulations,* the Chief of the Bureau of Ordnance is responsible to the Secretary of the Navy for the active planning, direction, coordination, and control of the Bureau as a whole and its field activities.

Deputy Chief. As principal adviser to the Chief, the Deputy Chief must be well informed regarding all matters of operation and policy within the Bureau. By authority delegated by the Chief, he may supervise all Bureau activities and act for the Chief.

Special assistants. At the time of this writing, the Chief of the Bureau has two special assistants, as follows:

The *Inspector General, Bureau of Ordnance,* is responsible for investigating efficiency, safety, industrial hygiene, and adherence to directives at all naval ordnance stations. Where necessary, he recommends corrective action.

The *Counsel for the Bureau* advises and serves the Bureau in all legal matters except patents. He coordinates all legal matters (other than patents) that pertain to the Bureau's mission and its accomplishment.

Management council. The division directors and the Deputy Chief—who acts as chairman—constitute a management council for the Bureau. The council considers and recommends beneficial changes in policy, control systems, and other matters of Bureau-wide interest. It discusses and coordinates management plans, policies, and objectives, bringing to this discussion the several divisional viewpoints.

Division directors. Subject to higher authority, each division director is responsible for organizing and administering the specialized activities of his division, and for coordinating its activities with those of other divisions.

The *Administrative Division* provides the following types of service: office equipment, military personnel, civilian personnel, management, and technical library. Its budgets for administrative expenses, administers security regulations, and provides for the editing, printing, and distribution of Bureau publications.

The *Financial Division* prepares, allocates, and coordinates the Bureau's budget. It reviews the budgetary requirements of the several divisions, maintains the Bureau's financial records, and develops accounting systems for use at ordnance field activities.

The *Planning and Progress Division* plans and coordinates matters involving logistics and mobilization, reports progress as compared with requirements in logistic matters, prepares the budget for logistics, and administers military aid to foreign governments.

The *Quality Control Division* promulgates and administers appropriate quality evaluation, inspection, and testing of all products manufactured for the Bureau.

As the central contracting office for the Bureau, the *Contract Division* is responsible for arranging finances, awarding contracts, supervising terminations, and paying contractors as necessary in carrying out the business of the several divisions.

The *Naval Ordnance Establishments Division* administers and coordinates all matters—including service requirements, facilities, personnel, industrial relations, management, and operation—that are involved in maintaining the various naval ordnance establishments.

The *Material Division* directs the procurement, distribution, maintenance, repair, alteration, replacement, and inventory control of all naval ordnance. It provides for the safe handling and surveillance of explosive ordnance. It also prepares manuals—or parts thereof—devoted to the operation and maintenance of naval ordnance.

The *Research Division* directs and implements the research, design, and development activities of the Bureau, whether these activities are carried out within the Ordnance Establishment, at universities, or by private contractors. It also coordinates pertinent research conducted by other government agencies. The *Patent Counsel for the Bureau* reports to the Chief of the Bureau through the director of the Research Division.

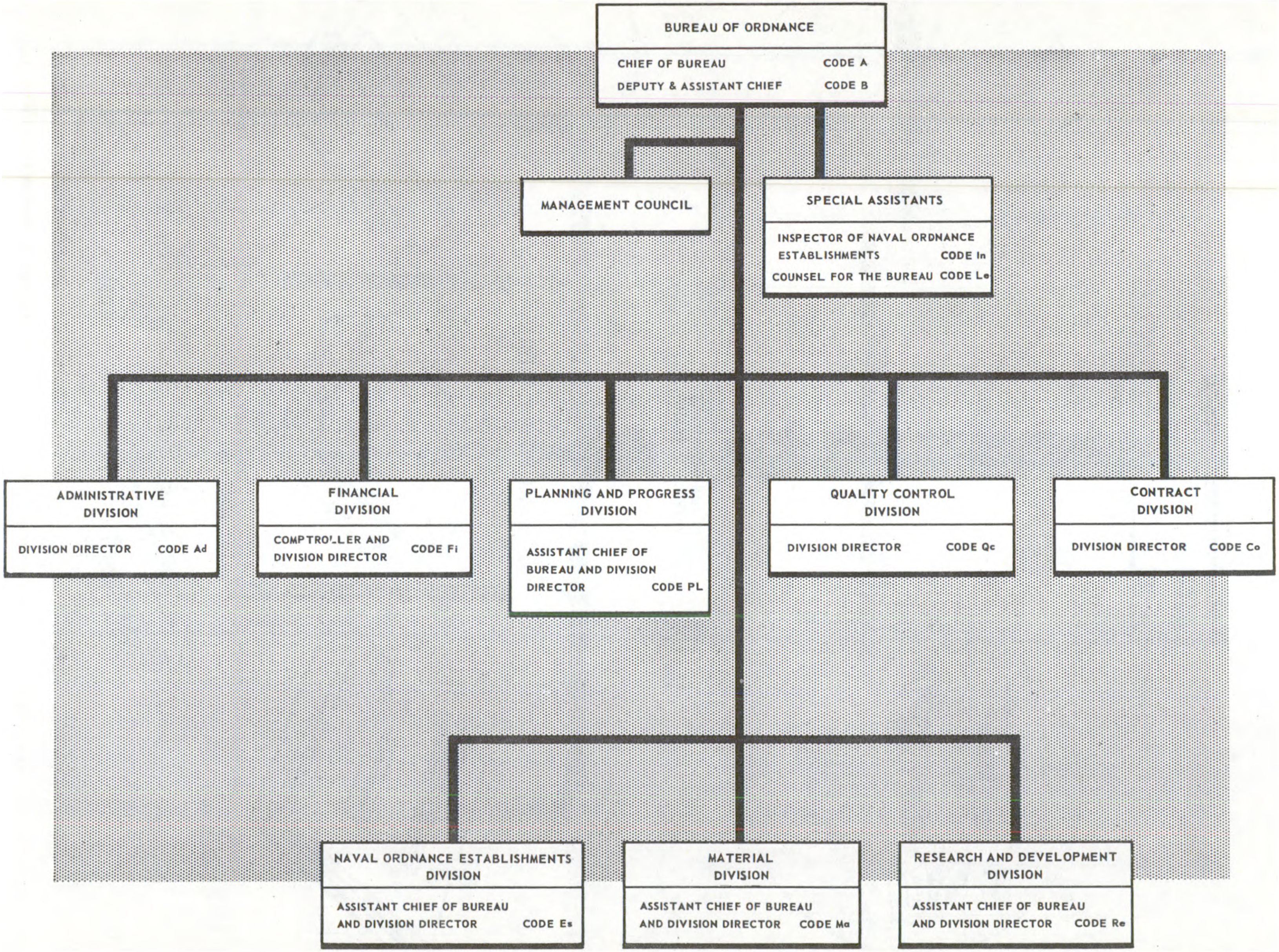

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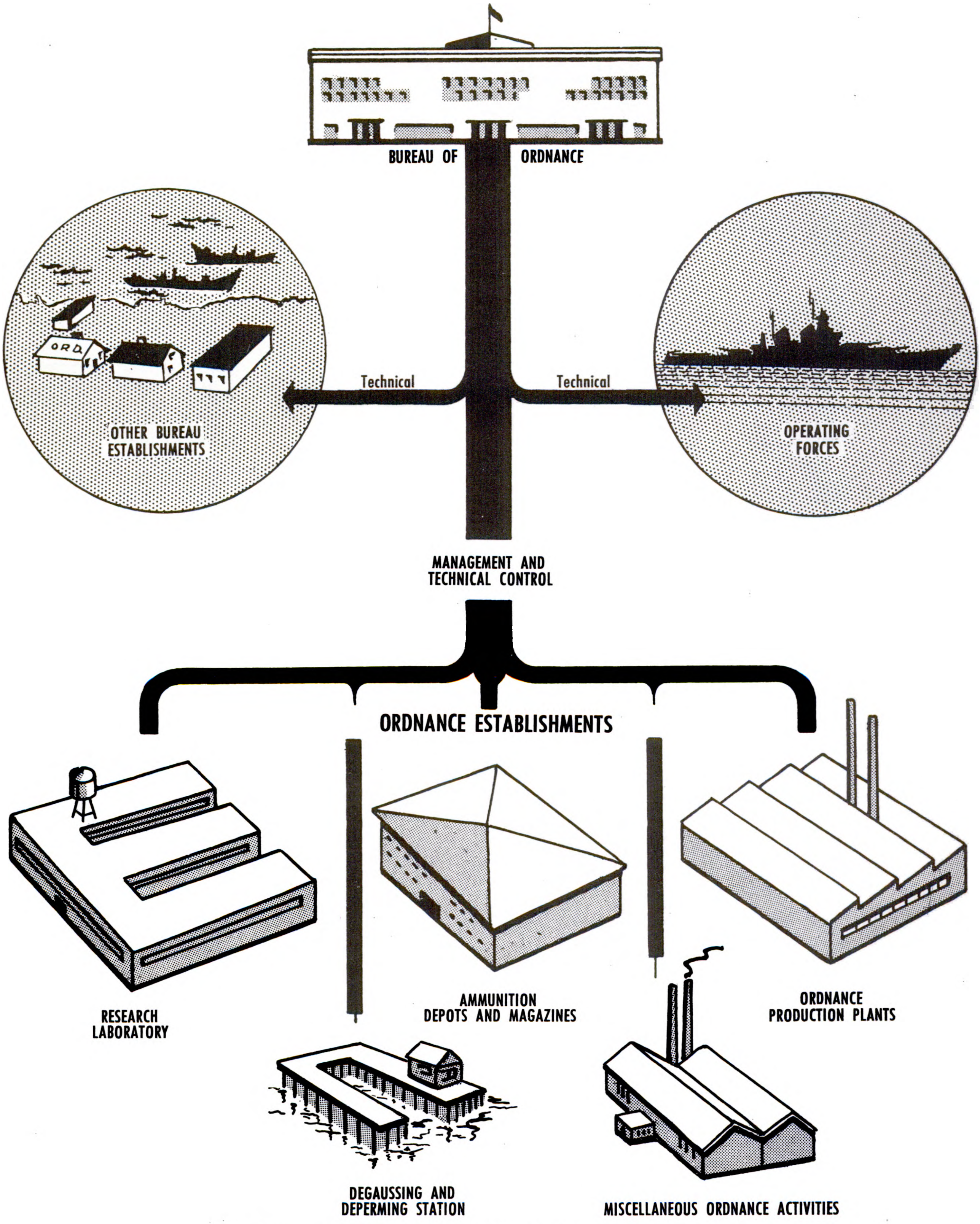
Figure G1.—Bureau of Ordnance organization.


BUREAU OF ORDNANCE
Technical
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OTHER BUREAU ESTABLISHMENTS
ORD.
OPERATING FORCES
MANAGEMENT AND TECHNICAL CONTROL
ORDNANCE ESTABLISHMENTS
RESEARCH LABORATORY
AMMUNITION DEPOTS AND MAGAZINES
ORDNANCE PRODUCTION PLANTS
DEGAUSSING AND DEPERMING STATION
MISCELLANEOUS ORDNANCE ACTIVITIES

FIGURE G2.—Controls exercised by the Bureau of Ordnance.

G2. Controls exercised by BuOrd

According to *Navy Regulations,* the Bureau of Ordnance is the center of authority and responsibility over naval ordnance affairs throughout the Naval Establishment and its contracting civilian plants.

By virtue of this responsibility, the Bureau of Ordnance exercises both management and technical control over activities with primary functions in ordnance. It also exercises technical control over the ordnance activities in those parts of the Naval Establishment that are not under BuOrd management control.

Figure G2 is a graphic representation of the controls exercised by the Bureau of Ordnance. Refer to this figure as you read the ensuing paragraphs on the two types of control.

Management control. The routine administration of non-military matters at a naval activity is usually referred to as management control. The scheduling of the workload in terms of personnel, money, and facilities is—for example—a function of management control. Another function is the establishment of administrative policies covering such matters as civilian personnel relations.

Figure G2 shows that the activities under management control of the Bureau include ordnance research laboratories, ammunition depots, production plants, and degaussing stations. This is a typical list, rather than an exhaustive one.

Technical control. The Bureau exercises control over the methods used in the manufacture, stowage, issue, and transportation of the gear under its special cognizance. This specialized control is known as technical control.

Naturally the ordnance field establishments are under the technical as well as the management control of the Bureau. At these establishments, BuOrd drawings and specifications set the standards for manufacturing processes. Directives and other communications specify what jobs are to be done and how the work shall be accomplished. The quality control program establishes manufacturing tolerances and methods of inspection.

The Bureau exercises technical control over ordnance work at activities that are not under its management control. For example, advanced bases are under management control of the Bureau of Yards and Docks, but ordnance magazines and shops at these bases are under technical control of the Bureau of Ordnance. Again, ordnance activities in the operating forces are under technical control of the Bureau of Ordnance.

At contracting civilian plants, the Bureau exercises technical control through contract provisions, drawings, specifications, and the inspection program.

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